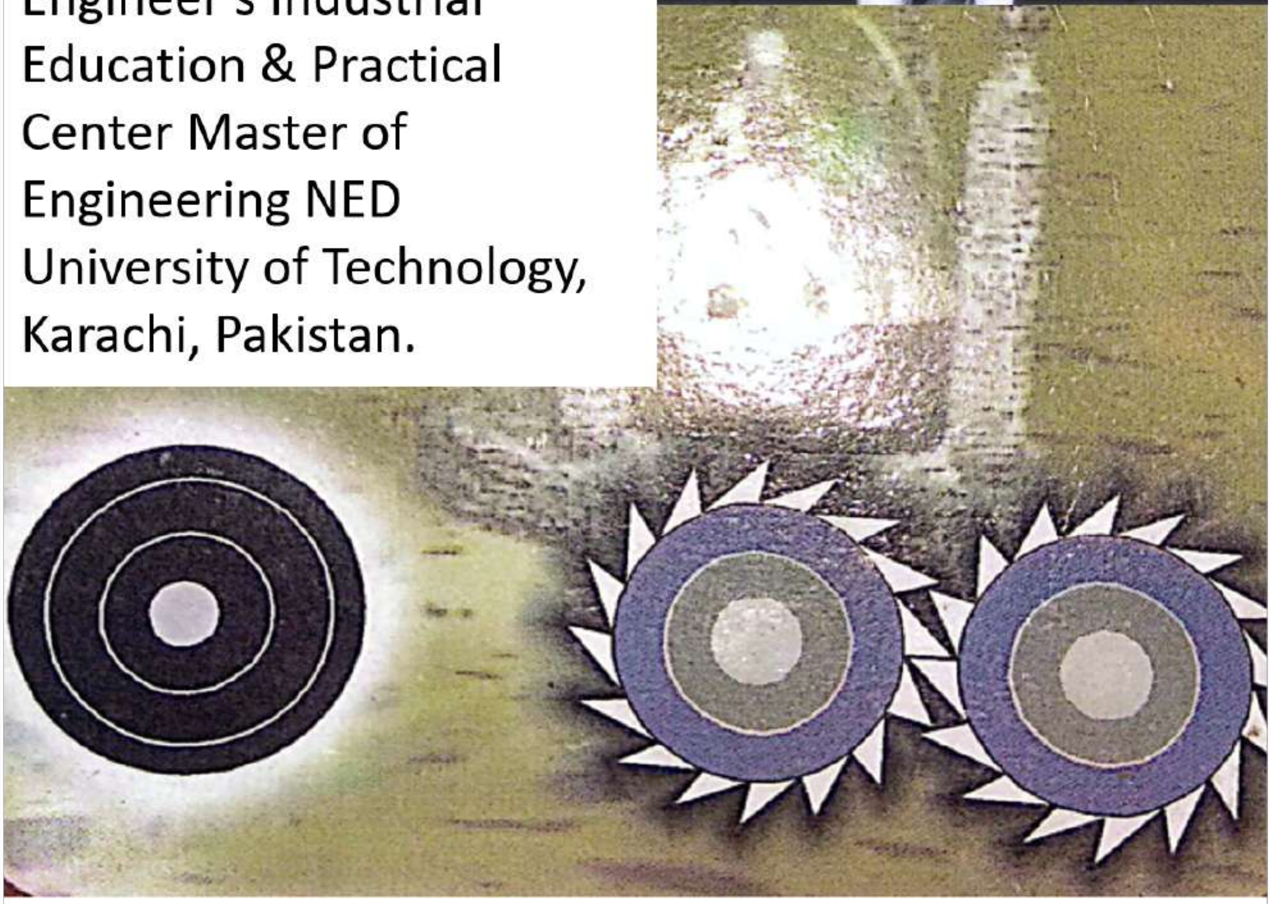
ENGINEERING FORMULAS

Compiled By
Engineer R Hasan

–

Research Scholar,
Languages Literatures
Born in Pakistan, HSK-3 Chinese, Goethe Institut Teilnahmebestatigung B1 datum 12.2020 - Research Scholar Alumni of EIEPC | Engineer's Industrial Education & Practical Center Master of Engineering NED University of Technology, Karachi, Pakistan.



ELECTRICAL ENGINEERING

General terms

S1

The most important electrical quantities and their units. – Basic rules

s 1 **Note regarding capital and small letters used as symbols**

Electrical engineering quantities that are independent of time are mainly denoted by capital letters. Quantities that vary with time are denoted by small letters or by capital letters provided with the subscript t.

Examples: formulae s 8, s 9, s 13

Exceptions: f, ω, $\hat{\imath}$, $\hat{u}$, P_{Fe10}

Electrical work W

Electrical work W is equivalent to mechanical work W as explained on M 1. Energy conversion, however, is subject to losses.

Units: J; Ws (wattsecond); kWh; MWh

$$1\ \mathrm{Ws} = 1\ \mathrm{Joule} = 1\ \mathrm{J} = 1\ \mathrm{Nm}$$

Further the following relation applies, using quantities explained on S1 and S2:

s 2 $$W = I\,V\,t = \frac{V^2}{R}\,t = I^2 R\,t$$

Electrical power P

Electrical power P is equivalent to mechanical power P, as explained on M 1. Energy conversion, however, is subject to losses.

Units: W (watt); kW; MW

$$1\ \mathrm{W} = 1\ \frac{\mathrm{J}}{\mathrm{s}} = 1\ \frac{\mathrm{Nm}}{\mathrm{s}}$$

Further the following relation applies, using quantities explained on S1 and S2:

s 3 $$P = \frac{V^2}{R} = I^2 R$$

Frequency f see L 1

Period T see L 1

Angular frequency ω, angular velocity ω see L 1

Current I

Is a base quantity (see preface and instructions)

Units: A (ampere); mA; kA

The current of 1 A has been defined by means of the attracting force which two parallel current-carrying conductors exert on each other.

continued on S 2

continued from S 1

Current density J

s 4 $$J = \frac{I}{A}$$

Applicable only where distribution of current I is uniform over cross section A.

Units: A/m^2; A/mm^2

Potential difference V

s 5 $$V = \frac{P}{I}$$

Units: V (volt); mV; kV

Where a direct current of 1 A through a conductor converts energy at a rate of 1 W, the voltage across this conductor is 1 V.

$$1\,\mathrm{V} = \frac{\mathrm{W}}{\mathrm{A}} = 1\,\frac{\mathrm{J}}{\mathrm{s\,A}} = 1\,\mathrm{A}\,\Omega = 1\,\frac{\mathrm{N\,m}}{\mathrm{s\,A}}$$

Resistance R

s 6 $$R = \frac{V}{I}$$ (Ohm's law)

Units: Ω (ohm); kΩ; MΩ

Where a voltage of 1 V across a conductor causes a current of 1 A to the flow through it, resistance is 1 Ω.

$$1\,\Omega = \frac{1\,\mathrm{V}}{1\,\mathrm{A}} = 1\,\frac{\mathrm{W}}{\mathrm{A}^2} = 1\,\frac{\mathrm{W}}{\mathrm{s\,A}^2} = 1\,\frac{\mathrm{N\,m}}{\mathrm{s\,A}^2}$$

Conductance G

Conductance G is the reciprocal of resistance R.

s 7 $$G = 1/R$$

Unit: 1/Ω

$$1/\Omega = 1\,\mathrm{Mho}$$

Quantity of electricity, charge Q

s 8 $$q = \int i\,dt$$ (see s 1)

For direct current:

s 9 $$Q = I\,t$$

Unit: C (coulomb)

$$1\,\mathrm{C} = 1\,\mathrm{A\,s}$$

continued on S 3

continued from S 2

Capacitance C

The capacitance C of a capacitor is the ratio of quantity of electricity Q stored in it and voltage V across it:

s 10 $$C = \frac{Q}{V}$$

Units: F (farad); μF; nF; pF

Where a capacitor requires a charge of 1 C to be charged to a voltage of 1 V, its capacitance is 1 F.

$$1\ \mathrm{F} = 1\ \frac{\mathrm{C}}{\mathrm{V}} = 1\ \frac{\mathrm{A\,s}}{\mathrm{V}} = 1\ \frac{\mathrm{A^2\,s}}{\mathrm{W}} = 1\ \frac{\mathrm{A^2\,s^2}}{\mathrm{J}} = 1\ \frac{\mathrm{A^2\,s^2}}{\mathrm{N\,m}}$$

Magnetic flux ϕ

s 11 $$\phi = \frac{1}{N}\int u\ dt \qquad \text{(see s 1)}$$

Here N is the number of turns of a coil and u the voltage induced, when the magnetic flux ϕ linked with the coil varies with time.

Units: Wb (weber) = V s = 10^8 M (maxwell)

1 Wb is the magnetic flux which, linking a circuit of 1 turn, induces in it a voltage of 1 V as it is reduced to zero at a uniform rate in 1 s.

Magnetic induction (flux density) B

The magnetic induction in a cross section A is:

s 12 $$B = \frac{\phi}{A}$$

Here A is the cross-sectional area traversed perpendicularly by the homogeneous magnetic flux ϕ.

Units: T (tesla); μT; nT; V s/m^2; G (gauss)

$$1\ \mathrm{T} = 1\ \frac{\mathrm{V\,s}}{\mathrm{m^2}} = 10^{-4}\ \frac{\mathrm{V\,s}}{\mathrm{cm^2}} = 10^4\ \mathrm{G} = 10^4\ \frac{\mathrm{M}}{\mathrm{cm^2}}$$

Where a homogeneous magnetic flux of 1 Wb perpendicularly traverses an area of 1 m^2, its magnetic induction is 1 T.

continued on S 4

continued from S 3

Inductance L

s 13
$$L = N\frac{\phi}{I} = N\frac{\phi_t}{i} \qquad \text{(see s 1)}$$

Here I is the current flowing through a coil of N turns and ϕ the magnetic flux linked with this coil.

Units: H (henry); mH

1 H is the inductance of a closed loop of one turn which, positioned in vacuum and passed through by a current of 1 A, encloses a magnetic flux of 1 Wb.

$$1\,\text{H} = 1\,\frac{\text{Wb}}{\text{A}} = 1\,\frac{\text{V s}}{\text{A}}$$

Magnetic field strength H

s 14
$$H = \frac{B}{\mu_0\,\mu}$$

Units: A/m; A/cm; A/mm; (Ampere Turn/m)

Magnetomotive force F

s 15
$$F = N\,I$$

Units: A; kA; mA; (Ampere Turn)

Magnetomotive force F_i in the i-th section of a magnetic circuit:

s 16
$$F_i = H_i\,l_i$$

here l_i is the length of this section.

s 17
$$\sum_{i=1}^{n} F_i = F$$

Reluctance S of a homogeneous section of a magnetic circuit:

s 18
$$S = \frac{F}{\phi} \qquad \left(\begin{array}{c}\text{equivalent to}\\ \text{Ohm's law for}\\ \text{magnetic circuits}\end{array}\right)$$

Units: 1/H = A/V s; (Ampere Turn/Wb)

---

for symbols see S 15

ELECTRICAL ENGINEERING

Electric circuits

S 5

Basic properties of electric circuits

Directions of currents, voltages, arrows representg. them

s 20 Direction of the current and of arrows representing positive currents in generator − → +
s 21 load + → −

s 22 Direction of the potential difference and of arrows representing positive voltages always + → −

Directions of arrows representg. currents or voltages

	where funct. of element (generator or load) as well as polarity is	determine directions of arrows	where calcul. results in a positive	negative
			value, direction with respect to arrow of current or voltage is	
s 23	known	as stated above	—	—
s 24	unknown	at random	equal	opposite

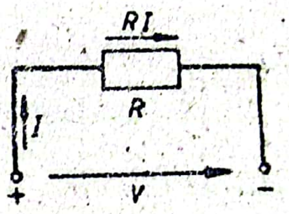
Special rule

Arrows representing voltage drop across a resistor and current causing it, should always be determined in same direction (as $R > 0$).

Ohm's Law

Current through a resistor:

s 25 $$I = \frac{V}{R} \qquad \text{(see also s 6)}$$



Resistance R of conductor

s 26 $$R = \frac{\varrho \cdot l}{A} = \frac{l}{\gamma A}$$

Resistance R of conductor at temperature ϑ (in degrees centigrade)

s 27 $$R = R_{20}\left[1 + \alpha(\vartheta - 20^{\circ}\mathrm{C})\right]$$

Electric heating of a mass m

s 28 $$V I t \eta = c\, m\, \Delta\vartheta$$

α : temperature coeff. (see Z 21)
γ : conductivity (see Z 1)
ϱ : resistivity (see Z 1)
c : specific heat (see Z 5)

$\Delta\vartheta$: temper. change
t : time
R_{20} : resistance at $\vartheta = 20^{\circ}\mathrm{C}$

continued on S 6

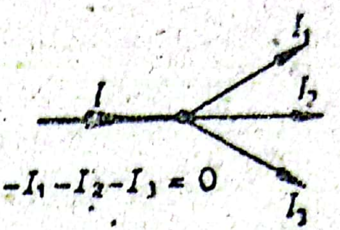
ELECTRICAL ENGINEERING

Resistor combinations

S 6

continued from S 5

1st Kirchhoff Law



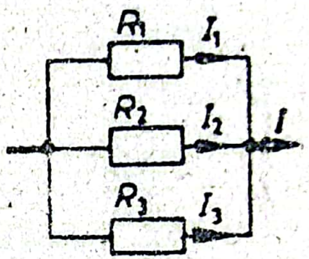
$I - I_1 - I_2 - I_3 = 0$

The algebraic sum of all currents entering a branch point (node) is zero.

9 $\Sigma I = 0$

Here currents $\left|\begin{array}{c}\text{into}\\ \hline \text{out of}\end{array}\right|$ the node are considered $\left|\begin{array}{c}\text{positive}\\ \hline \text{negative}\end{array}\right|$

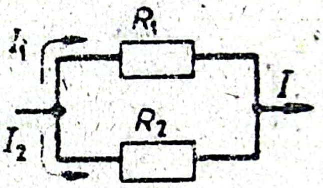
Ratio of currents



Where several resistors are connected in parallel, total current and partial currents are inversely proportional to their respective resistances.

s 30 $I : I_1 : I_2 : I_3 = \frac{1}{R} : \frac{1}{R_1} : \frac{1}{R_2} : \frac{1}{R_3}$

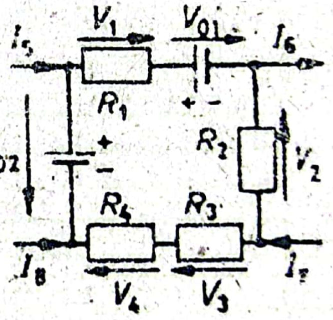
Current division



Partial currents of 2 resistors connected in parallel:

s 31 $I_1 = I \frac{G_1}{G_1 + G_2} = I \frac{R_2}{R_1 + R_2}$

2nd Kirchhoff Law



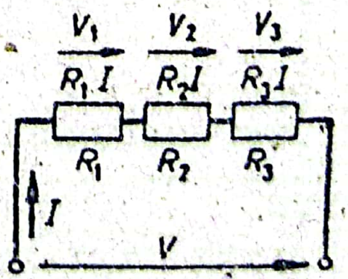
$V_1 + V_{01} - V_2 + V_3 + V_4 - V_{02} = 0$

The algebraic sum of all voltages around a closed mesh (loop) is zero.

$\Sigma V = 0$

s 32 Here voltages traversed in accordance with (opposite to) direction of arrow are considered positive (negative).

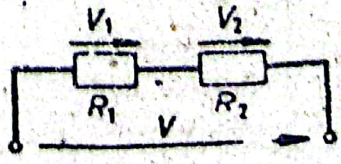
Ratio of voltages



Where several resistors are connected in series, the ratio of partial voltages is equal to the ratio of the respect. resistances.

s 33 $V_1 : V_2 : V_3 = R_1 : R_2 : R_3$

Voltage divider



Partial voltages across 2 resistors connected in series:

s 34 $V_1 = V \frac{G_2}{G_1 + G_2} = V \frac{R_1}{R_1 + R_2}$

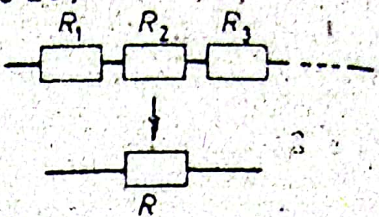
Resistor combinations

Series connection

Total resistance R (according to s 26)

generally:

s 35 $$R = R_1 + R_2 + R_3 + \dots$$



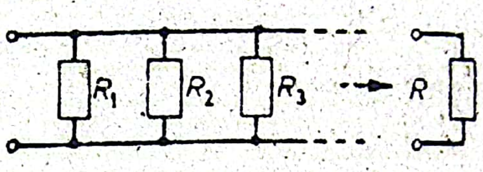
for n equal resistances R:

s 36 $$R = nR$$

Parallel connection

Total resistance R (according to s 30)

generally:



s 37 $$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \dots$$

s 38 $$G = G_1 + G_2 + G_3 + \dots$$

for 2 resistances:

s 39 $$R = \frac{R_1 R_2}{R_1 + R_2}$$

s 40 $$= \frac{1}{G_1 + G_2}$$

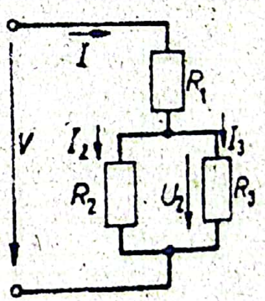
for 3 resistances:

$$R = \frac{R_1 R_2 R_3}{R_1 R_2 + R_2 R_3 + R_1 R_3}$$

$$= \frac{1}{G_1 + G_2 + G_3}$$

Multiple connection

A multiple connection of several known resistances is subdivided into parallel and series connections, proceeding outwards. These are separately converted as to be conveniently combined again, e.g.:

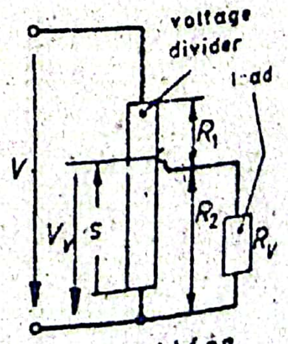


s 41 $$I = \frac{R_2 + R_3}{R_1 R_2 + R_1 R_3 + R_2 R_3} V = \frac{G_1 (G_2 + G_3)}{G_1 + G_2 + G_3} V$$

s 42 $$I_3 = \frac{R_2}{R_1 R_2 + R_1 R_3 + R_2 R_3} V = \frac{G_1 G_3}{G_1 + G_2 + G_3} V$$

s 43 $$U_2 = \frac{R_2 R_3}{R_1 R_2 + R_1 R_3 + R_2 R_3} V = \frac{G_1}{G_1 + G_2 + G_3} V$$

Voltage divider



Voltage dividers are used for reducing voltages.

s 44 $$V_V = \frac{R_2 R_V}{R_1 R_2 + R_1 R_V + R_2 R_V} V$$

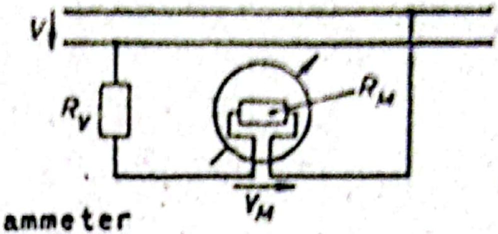
For applications, where V_V has to be approx. proportional to s, the condition $R_V \geq 10(R_1 + R_2)$ has to be satisfied.

s : distance of sliding contact from zero position

Applications in electrical measurements

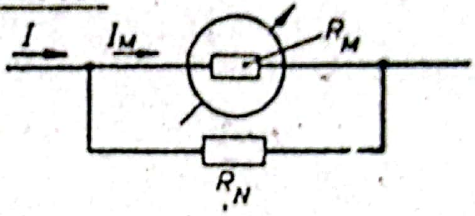
Extending the range of a voltmeter

s 45 $$R_V = R_M\left(\frac{V_{max}}{V_{M\,max}} - 1\right)$$



Extending the range of an ammeter

s 46 $$R_N = R_M\,\frac{I_{M\,max}}{I_{max} - I_{M\,max}}$$



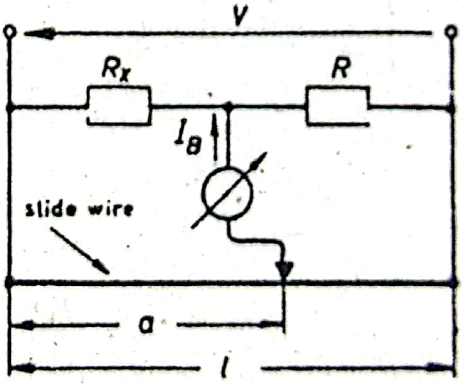
Wheatstone bridge for measuring an unknown resistance R_x

A slide-wire Wheatstone bridge may be used for measuring resistances of between 0·1 and 10^6 ohms. The calibrated slide wire is provided with a scale reading $a/(l-a)$. The sliding contact is adjusted, until the detector current I_B is zero. Then

s 47 $$\frac{R_x}{R} = \frac{a}{l - a}$$

and hence

s 48 $$R_x = R\,\frac{a}{l - a}$$



Wheatstone bridge used as a primary element

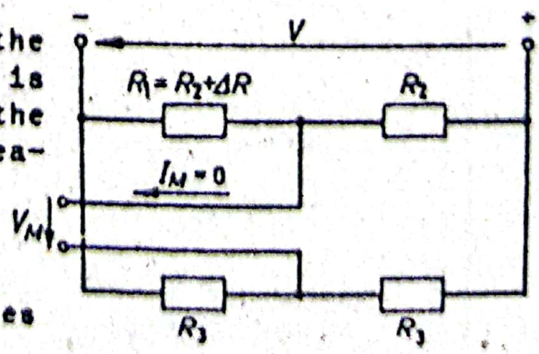
In many types of measuring equipment Wheatstone bridges serve as comparators for evaluating voltage differences.

R_1 : sensor resistor, the variation of which is proportional to the quantity x to be measured (e.g. temp., distance, angle etc.)

R_2 : zero value of R_1

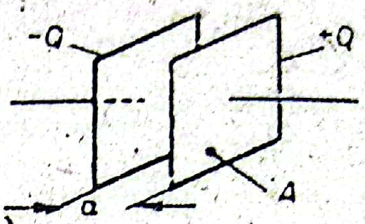
Approx. the relat. applies

s 49 $$V_M \sim \Delta R \sim x$$



Electric field

Capacitance C of a capacitor



s 50 $$C = \frac{\varepsilon_0 \varepsilon_r A}{a}$$

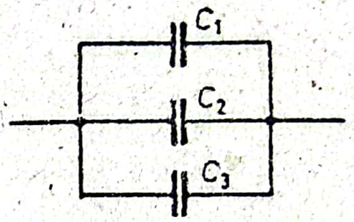
Quantity of electricity Q (see s 8)

Electrical work W_C stored in an electric field

s 51 $$W_C = \frac{1}{2} C V^2$$

Capacitors connected in parallel

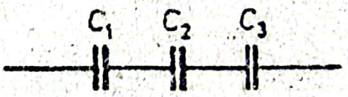
Where capacitors are added in parallel, the total capacitance C increases.



s 52 $$C = C_1 + C_2 + C_3$$

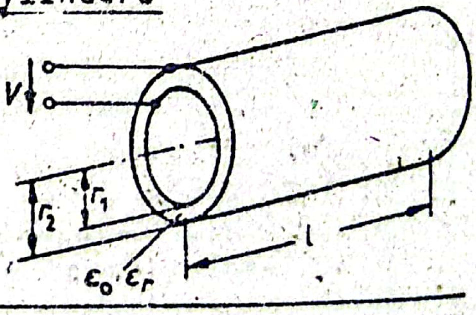
Capacitors connected in series

Where capacitors are added in series, the total capacitance C decreases.



s 53 $$\frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}$$

Capacitance of two coaxial cylinders



s 54 $$C = 2\pi \varepsilon_0 \varepsilon_r \frac{l}{\ln \frac{r_2}{r_1}}$$

ε_r : relative permittivity (see Z 2)
ε_0 : absolute permittivity ($\varepsilon_0 = 8{\cdot}86 \times 10^{-12}$ A s/V m)
A : plate area (one side)
a : thickness of dielectric
r_1 : radius of inner cylinder
r_2 : radius of outer cylinder
l : length of cylinders

ELECTRICAL ENGINEERING | S 10

Electro-magnetic rules

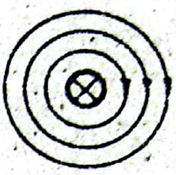
Deflection of a magnetic needle

s 55 The N-pole of a magnetic needle is attracted by a magnetic S-pole and repelled by a magnetic N-pole.

Fixed conductors and coils

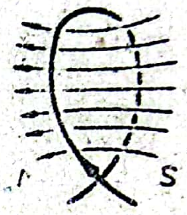
s 56 **Magn. flux about a current-carrying conductor**

Assuming a corkscrew were screwed in the direction of the current, its direction of rotation would indicate the direction of the lines of magnetic flux.



s 57 **Magnetic flux within a current-carrying coil**

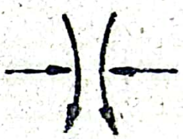
Assuming a corkscrew were rotated in the direction of the current through the coil, the direction of its axial motion would indicate the direction of the lines of magnetic flux through the coil.



Movable conductors and coils

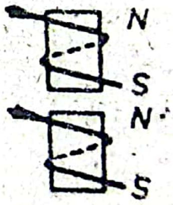
s 58 **Parallel conductors**

Two parallel conductors carrying currents of the same direction attract. Two carrying currents of opposite direction repel each other.



s 59 **Two coils facing each other**

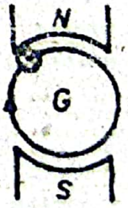
Where two coils positioned face to face carry currents of the same direction, they attract, where they carry currents of opposite directions, they repel each other.



Machines

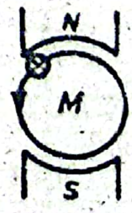
s 60 **Right Hand Rule** (generator)

Where the thumb points in the direction of the magnetic flux and the middle finger in the direction of motion, the index finger indicates the direction of current flow.



s 61 **Left Hand Rule** (motor)

Where the thumb points in the direction of the magnetic flux and the index finger in the direction of current flow, the middle finger indicates the direction of motion.



Quantities of magnetic circuits

Magnetic flux ϕ

s 62 $$\phi = \frac{F}{S} = \frac{N\,I}{R_m}$$ (see also s 11)

Magnetic induction (flux density) B

s 63 $$B = \frac{\phi}{A} = \mu_r \mu_0 H$$ (see also s 12)

Inductance L

s 64 $$L = N\frac{\phi}{I} = N^2\Lambda = \frac{N^2}{R_m}$$ (see also s 13)

For calculation of L see also s 134 through s 140

Magnetic field strength H (Magnetising force)

s 65 $$H = \frac{B}{\mu_r \mu_0} = \frac{F_i}{l_i}$$ (see also s 14)

Magnetomotive force F

s 66 $$F = N\,I = \sum_{i=1}^{n} F_i$$ (see also s 15)

Magnetomotive force F_i

s 67 $$F_i = H_i\, l_i$$ (see also s 16)

Reluctance S

s 68 $$S = \frac{F}{\phi} = \frac{l}{\mu_r \mu_0 A}$$ (see also s 18)

Energy W_m stored in a magnetic field

s 70 $$W_m = \frac{1}{2} N\,I\,\phi = \frac{1}{2} L\,I^2$$

Leakage flux ϕ_L

Part of the total magnetic flux ϕ leaks through the air and is thus lost for the desired effect. ϕ_L is related to the useful flux ϕ_u. Hence the leakage

s 71 coefficient is: $$\sigma = \frac{\phi}{\phi_u} = \frac{\text{total flux}}{\text{useful flux}}$$ (1·15...1·25)

CamScanner

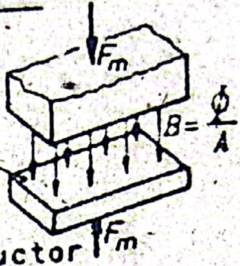
ELECTRICAL ENGINEERING

Magnetic field

S 12

The magnetic field and its forces

Force F_m acting between magnetic poles



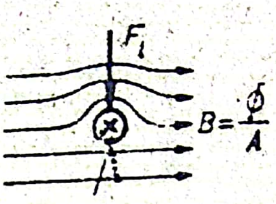
In the direction of the magnetic flux a tensile force F_m occurs:

73 $$F_m = \frac{1}{2}\frac{B^2 A}{\mu_0} \quad \text{or} \quad F_m \approx 40\left(\frac{B}{T}\right)^2 \frac{A}{cm^2}\ N$$

Force F_l acting on a current-carrying conductor

A conductor carrying a current I encounters a transverse force F_l over its length l perpendicular to the lines of magnetic flux.

74 $$F_l = B\,l\,I \quad \text{or} \quad F_l = \frac{B}{T}\,\frac{l}{m}\,\frac{I}{A}\ N$$



When applied to the armature of a DC-machine, the moment is:

75 $$M_i = \frac{1}{2\pi}\,\phi\,I\,\frac{p}{a}\,z$$

(ϕ : flux per pole)

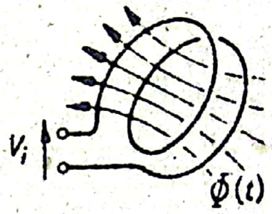
76

Induced voltage V_i (induction law)

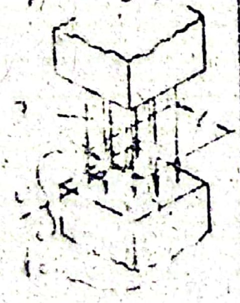
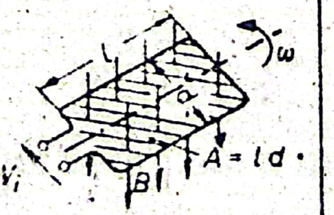
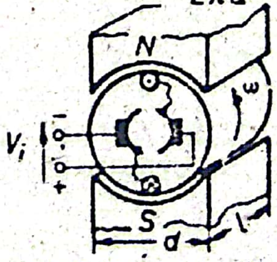
Where the magnetic flux ϕ threading a coil of N turns varies with time a voltage

76 $$V_i = N\,\frac{d\phi}{dt}$$

is induced in the coil (see also S 11)



voltage induced by

	motion of conduct perpendicular to flux	rotation of conductor loop in magnetic field	rotat. of generator armature in magnetic field
77	$V_i = B\,l\,v$	$V_i = \omega\,\phi_{max} \times \sin(\omega t)$	$V_i = \phi\,n\,z\,\frac{p}{a}$
78		$\phi_{max} = l\,d\,B$	$= l\,d\,B\,\frac{z\,p}{2\pi a}\,\omega$
79			

80 **Voltage V_i due to self-induction:** $V_i = L\,dI/dt$

for explanations see S 15

For symbols see S 15

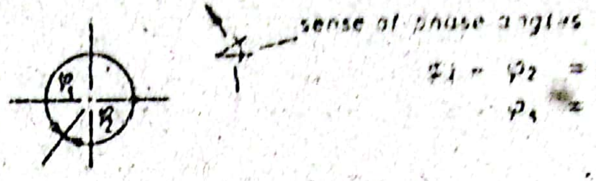
General terms relating to alternating-current circuits

Sense of phase angles

In vector diagrams arrows are sometimes used to represent phase angles. Here counter-clockwise arrows are taken positive, clockwise arrows negative.

Example

s 81

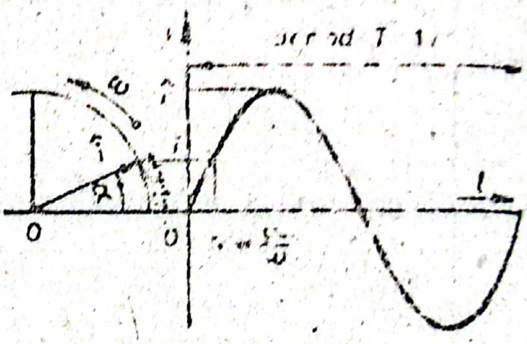


$\varphi_1 - \varphi_2 = 360^\circ =$

$\varphi_1 \hat{=} \varphi_2$

Peak values (see also s 1)

Current i and voltage v of an alternating current vary periodically with time t, usually sinusoidally. The maximum values $\hat{i}$ and $\hat{v}$ are called peak values. At an angular frequency $\omega = 2\pi f$ the angle covered in time t is:



s 82 $$\alpha = \omega t = 2\pi f t$$

Hence at this time

s 83 the current is $i = \hat{i} \sin(\omega t) = \hat{i} \sin\alpha$

s 84 the voltage is $v = \hat{v} \sin(\omega t) = \hat{v} \sin\alpha$

Root-mean-square (rms) values

These are used for practical calculations and are usually indicated by meters.

	generally	for sine waves
s 85	$I = I_{eff} = \sqrt{\frac{1}{T}\int_0^T i^2\,dt}$	$I = I_{eff} = \frac{\hat{i}}{\sqrt{2}}$
s 86	$V = V_{eff} = \sqrt{\frac{1}{T}\int_0^T v^2\,dt}$	$V = V_{eff} = \frac{\hat{v}}{\sqrt{2}}$

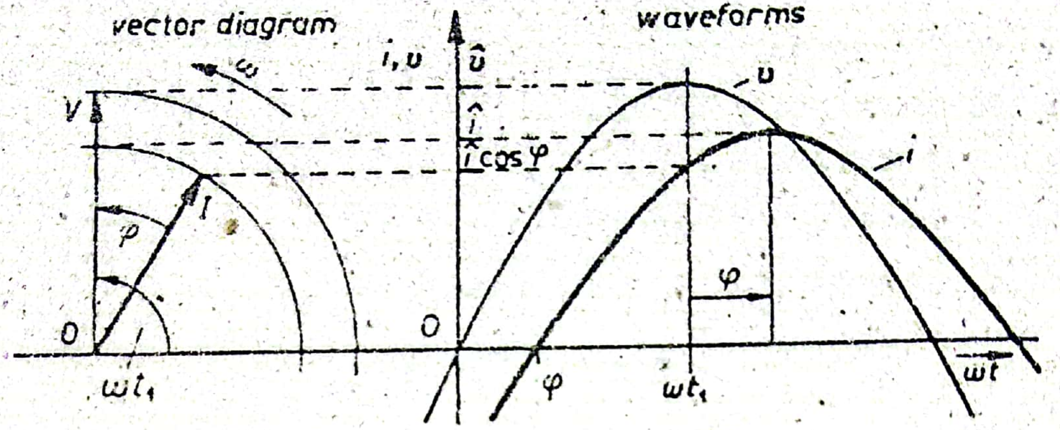
s 87 With these values the relation $P = V I$ also applies for alternating current, if $\cos\varphi = 1$ (see s 99).

continued on S

continued from S 13

Phase shift, phase angle φ

Where different kinds of load (resistance, inductance and/or capacitance) are present in an alternating-current circuit, a phase shift between current and voltage occurs.



88 $\upsilon = \hat{\upsilon}\,\sin(\omega t)$ $\qquad$ $i = \hat{\imath}\,\sin(\omega t - \varphi)$

Q factor, damping factor tan δ, loss angle δ

The Q factor of a circuit has been defined by:

89 $$Q = \frac{2\pi\hat{W}}{W_{VP}}$$

Here $\hat{W}$ is the peak value of the energy stored in the circuit and W_{VP} the loss energy dissipated in one period.

The reciprocal of Q factor is called damping factor

90 $$\tan\delta = 1/Q \qquad (\delta \text{ is the loss angle})$$

For a choke (s 109 and s 112) and for a capacitor-resistor combination (s 110 and s 113) this definition results in the simple relations:

91 $Q = \tan\varphi$ $\quad$ | $\tan\delta = 1/Q = 1/\tan\varphi$

92 $\delta = 90^\circ - \varphi$ $\quad$ | $= V_w/V_b$ (for series connection)

93 $\quad$ | $= I_w/I_b$ (for parallel connection)

For formulae regarding tan φ see S 16 and S 17. Formulae s [illegible] and s 123 applicable for resonant circuits are not so simple.

ELECTRICAL ENGINEERING

Alternating current

Basic equations for single phase alternating current

s 94 Impedance Z see S 16 and S 17

s 95 Voltage across impedance $V = I\,Z$

s 96 Current through impedance $I = \frac{V}{Z}$

s 97 Apparent power $P_s = V\,I = \sqrt{P^2 + P_q^2} = I^2 Z$

s 98 Reactance $X = Z \sin\varphi$

s 99 Active power $P = V\,I \cos\varphi = I^2 R$

s 100 Reactive power $P_q = V\,I \sin\varphi = I^2 X$

s 101 Power factor $\cos\varphi = \frac{P}{V\,I} = \frac{P}{P_s}$

s 102 Alternating magnetic flux in a coil $\hat{\Phi} = \frac{V_L}{4 \cdot 44\,N\,f}$

s 103 μ_0 : absolute permeability ($\mu_0 = 4\pi \times 10^{-7}$ V s/A m)

μ_r : relative permeability
(for vacuum, gases, fluids, and most solids:
$\mu_r \approx 1$,
for magnetic materials take μ_r from Z 3)

a : number of parallel paths through winding
l : length of magnetic circuit
N : number of turns of coil
p : number of pole pairs
z : number of conductors

R_R	resistance in	series	equivalent circuit of choke
R_P		parallel	
L_R	inductance in	series	
L_P		parallel	

Explanations concerning S 12 (v_i of self-induction)

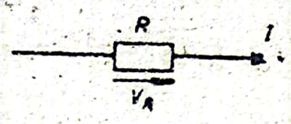
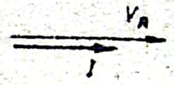
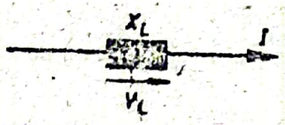
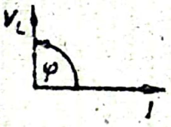
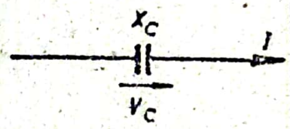
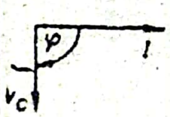
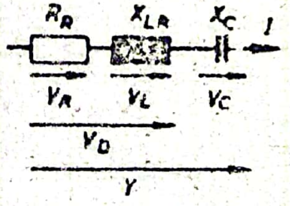
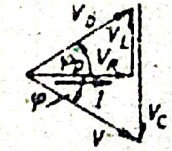
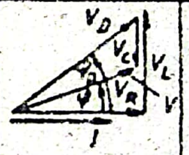
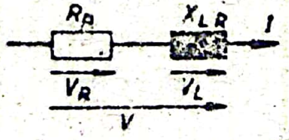
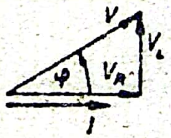
Where the current i flowing through a coil change with time, the magnetic field caused by this current also changes. Thereby a voltage v_i of self-induction is induced in the coil. Its direction i such that it counteracts the instantaneous chang of current (Lenz's law).

ELECTRICAL ENGINEERING

Alternating current

S 16

Components, series- and parallel connections carrying alternating current

	component		symbol	vector diagram	phase		impedance	tan φ =
					relat.	angle		
s 104	**resistive** lamp, coil with bi-filar winding				I and V in phase	$\varphi = 0^\circ$	$Z = R$	0
s 105	**inductive** ideal inductance				I lags V by 90°	$\varphi = 90^\circ$	$Z = X_L = \omega L$	∞
s 106	**capacitive** capacitor				I leads V by 90°	$\varphi = -90^\circ$	$Z = X_C = \frac{1}{\omega \cdot C}$	∞
s 107	**resist+ induct+ capacit. conn. in series**	$\omega L_R < \frac{1}{\omega C}$	 R_R X_{LR} X_C I V_R V_L V_C V_D V		I leads V	$-90^\circ < \varphi < 0^\circ$	$Z = \sqrt{R_R^2 + \left(\omega L_R - \frac{1}{\omega C}\right)^2}$	$\frac{\omega L_R - \frac{1}{\omega C}}{R_R}$
s 108	choke in series with capacit.	$\omega L_R > \frac{1}{\omega C}$			I lags V	$0^\circ < \varphi < 90^\circ$		
s 109	resistive and inductive in series choke				I lags V by less than 90°	$0^\circ < \varphi < 90^\circ$	$Z = \sqrt{R_R^2 + (\omega L_R)^2}$	$\frac{\omega L_R}{R_R}$

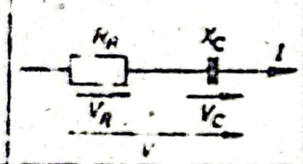
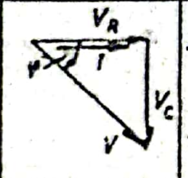
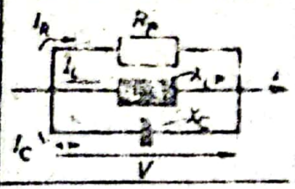
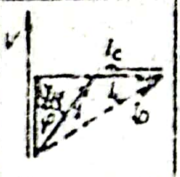
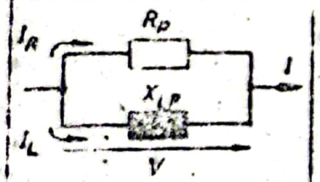
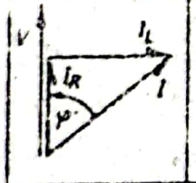
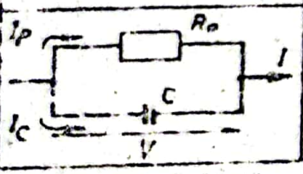
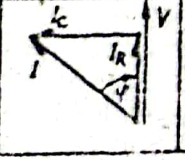
continued S 17

ELECTRICAL ENGINEERING

Alternating current

S 17

continued from S 16

	kind of load	symbol	vector diagram	phase relat.	phase angle	impedance	$\tan\varphi =$
s 110	resist. + capac. in series resistor in series with capacitor			I leads V by less than 90°	$-90° < \varphi < 0°$	$Z = \sqrt{R_R^2 + \left(\frac{1}{\omega C}\right)^2}$	$-\frac{1}{R_R \omega C}$
s 111	resist.+induct. and capacit. in parallel choke + capacit. in parallel			I leads or lags V depending on values	$-90° < \varphi < 90°$	$Z = \frac{1}{\sqrt{\left(\frac{1}{R_p}\right)^2 + \left(\frac{1}{\omega L_p} - \omega C\right)^2}}$	$R_p\left(\frac{1}{\omega L_p} - \omega C\right)$
s 112	resistive and inductive in parallel choke			I lags V	$0° < \varphi < 90°$	$Z = \frac{1}{\sqrt{\left(\frac{1}{R_p}\right)^2 + \left(\frac{1}{\omega L_p}\right)^2}}$	$\frac{R_p}{\omega L_p}$
s 113	resist.+ capac. in parallel resistor + capacit. in parall.			I leads V	$-90° < \varphi < 0°$	$Z = \frac{1}{\sqrt{\left(\frac{1}{R_p}\right)^2 + (\omega C)^2}}$	$-R_p \omega C$

s 114 The given values R and L of a choke always are the frequency-independent values R_R and L_R of the series equivalent circuit (see s 109). However, where a choke is connected in parallel with a capacitor, it is desirable to use the parallel equivalent circuit of the choke (s 112). The frequency-dependent values R_p and L_p contained therein may be calculated by:

$$R_p = R_R + \frac{(\omega L_R)^2}{R_R}$$

s 115

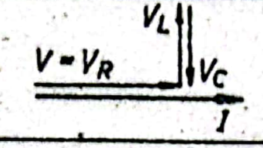
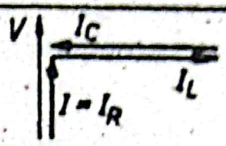
$$L_p = L_R + \frac{R_R^2}{\omega^2 L_R}$$

ELECTRICAL ENGINEERING

Alternating current

S 18

Resonant circuits

		series-resonant circuit	parallel-resonant circuit
	symbol and general vector diagram	see s 107	see s 111
	vector diagram at resonance		
s 116 s 117 s 118	resonance condition	$V_L = V_C$ $\omega_r L_R - \frac{1}{\omega_r C} = 0$ $\omega_r^2 L_R C = 1$	$I_L = I_C$ $\frac{1}{\omega_r L_P} - \omega_r C = 0$ $\omega_r^2 L_P C = 1$
s 119	resonant frequency	$f_r = \frac{1}{2\pi\sqrt{L_R C}}$	$f_r = \frac{1}{2\pi\sqrt{L_P C}}$
		where line frequ. $f = f_r$, resonance occurs	
s 120 s 121	current at resonance	$I_r = \frac{V}{R_R}$ at $V_b = V_L - V_C = 0$ $\varphi = 0$	$I_r = \frac{V}{R_P} = \frac{R_R C V}{L_R}$ at $I_b = I_L - I_C = 0$ $\varphi = 0$
s 122	Q factor	$Q_R = \frac{\omega_r L_R}{R_R} = \frac{1}{\omega_r C R_R}$	$Q_P = \omega_r C R_P = \frac{R_P}{\omega_r L_P}$
s 123	loss angle δ from	$\tan \delta_R = \frac{1}{Q_R} = \frac{R_R}{\omega_r L_R}$	$\tan \delta_P = \frac{1}{Q_P} = \frac{1}{\omega_r C R_P}$
s 124	wavelength	$\lambda = \frac{c}{f_r} = \frac{300 \cdot 10^6 \text{ m}}{f_r \text{ s}}$	
s 125	resonant period	$T_r = 2\pi\sqrt{L_R C}$	$T_r = 2\pi\sqrt{L_P C}$

Wave trap.

A parallel resonant circuit has its maximum impedance Z_{max} at its resonant frequency. Therefore it acts as a rejector for currents of this frequency.

s 126 $Z_{max} = R_P = \frac{L_R}{R_R C}$ and current $I = \frac{V}{Z_{max}}$

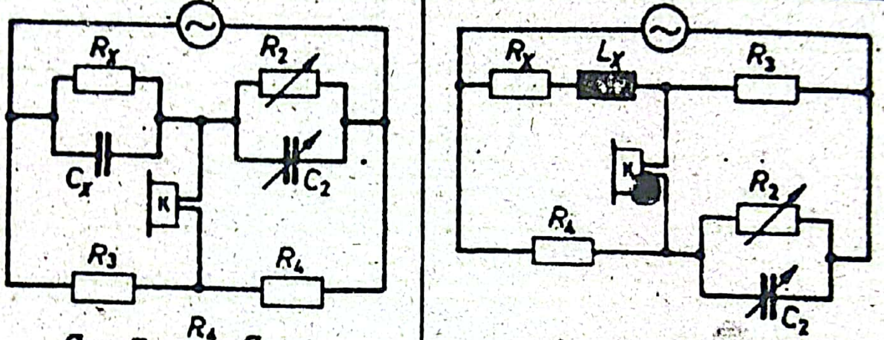
for symbols see S 15

Alternating-current bridge

AC bridges are used to determine capacitances and inductances. For balancing the bridge variable capacitor C_2 and resistor R_2 are adjusted until the sound in the low resistance headphone K reaches its minimum or vanishes. The following circuits are independent of frequency.

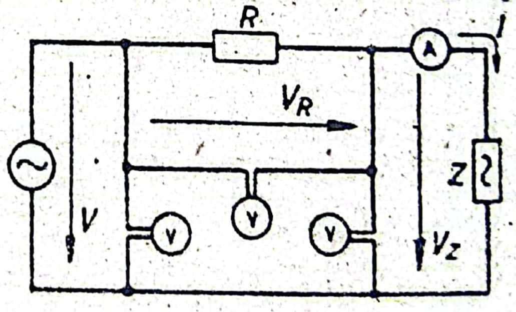
measurement of

capacitance | inductance



	capacitance	inductance
s 127	$C_x = \frac{R_4}{R_3} C_2$	$L_x = C_2 R_3 R_4$
s 128	$R_x = \frac{R_3}{R_4} R_2$	$R_x = \frac{R_3 R_4}{R_2}$
s 129	$\tan\delta_x = \frac{1}{R_x \omega C_x}$	$\tan\delta_x = \frac{R_x}{\omega L_x}$

Determination of an unknown impedance by measuring the voltages across this impedance and an auxiliary resistor:



s 130 $$P_{WZ} = \frac{V^2 - V_R^2 - V_Z^2}{2R}$$

s 131 $$\cos\varphi_Z = \frac{P_{WZ}}{V_Z I}$$

s 132 $$Z = \frac{V_Z}{I}$$

s 133 select auxiliary resistor R such that $V_R \approx |V_Z|$

C_x : unknown capacitance | δ_x : loss angle, see S 14
L_x : unknown inductance | $R_{2..4}$: known resistances
R_x : unknown restistance of coil or capacitor
C_2, : C_4 : calibrated adjustable capacitances
Z : unknown impedance (inductive or capacitive)

Inductance L from impedance and resistance

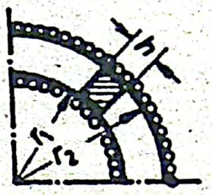
Calculating L from impedance and resistance

s 134 Pass an alternating current $(J = I/A \approx 3\ \mathrm{A/mm^2})$ through a coil and measure the terminal voltage V, current I, active power P:

s 135 impedance $Z = \frac{V}{I}$; resistance $R = \frac{P}{I^2}$

s 136 $$L = \frac{1}{\omega}\sqrt{Z^2 - R^2}$$

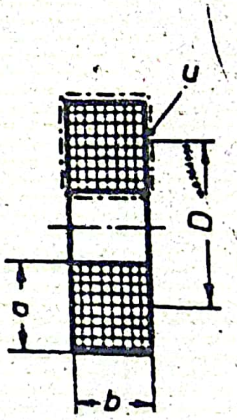
Calculating L for a toroidal coil



s 137 $$L = \frac{\mu_0 h N^2}{2\pi} \ln \frac{r_2}{r_1}$$

Calculating L for a square coil

armatures must be circular



	$\frac{D}{u}$	inductance
s 138	< 1	$L = 1{\cdot}05 \frac{D}{\mathrm{m}} N^2 \sqrt[4]{\left(\frac{D}{u}\right)^3}\ \mu\mathrm{H}$
s 139	> 1	$L = 1{\cdot}05 \frac{D}{\mathrm{m}} N^2 \sqrt{\frac{D}{u}}\ \mu\mathrm{H}$
s 140	$\geqq 3$	values become unreliable

$$1\ \mu\mathrm{H} = 10^{-6}\ \frac{\mathrm{V\,s}}{\mathrm{A}}$$

a : thickness of winding
A : cross section of wire
b : width of coil
d_a : external diameter of wire and insulation
D : mean diameter of coil
l_0 : internal length of armature winding
s 141 l_m : mean length of armature winding $(l_m = l_0 + \pi a)$
N : number of turns
u : circumference of coil cross section
α : ratio $a : b$
s 142 β : degree of loosening of turns $\left(\beta = \frac{a \cdot b}{N \cdot d_a^2}\right)$

Non-magnetic coils with specified inductance L

High frequency coils

	$\frac{D}{u}$	formula
s 143	<1	$\left(\frac{D}{m}\right)^{3.5} N^{3.25} = \frac{1}{39}\left(\frac{d_a}{m}\right)^{1.5}\left(\frac{L}{H}\right)^{2} \cdot 10^{-22}$
s 144	>1	$\left(\frac{D}{m}\right)^{3} N^{3.5} = \frac{1}{55}\left(\frac{d_a}{m}\right)\left(\frac{L}{H}\right)^{2} \cdot 10^{-22}$

here:

$$d_a = \frac{u}{2\sqrt{N}}$$

$$= d_a(1+\alpha)\sqrt{\frac{\beta}{\alpha}}$$

Low frequency coils

Assuming that

s 145 $\beta = 1$ and $D = u$, then

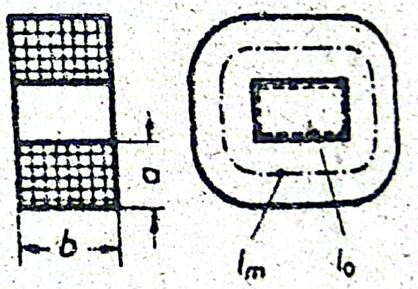
s 146 $$N \approx 975\times10^{3}\sqrt{\frac{L}{H}\,\frac{m}{D}}$$

s 147 $$a = \frac{1}{4}\left(u \pm \sqrt{u^2 - 16\,N\,d_a^2}\right); \qquad b = \frac{u}{2} - a$$

Calculation of number of turns N of a coil

From cross section

s 148 $$N = \frac{a\,b}{d_a^2}$$

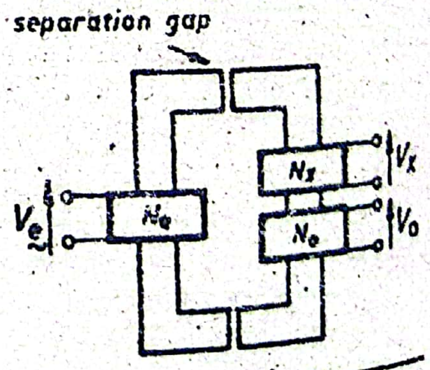


From resistance

s 149 $$N \approx \frac{R\,A}{\varrho\,l_m}$$

Using reference coil

Position unknown coil of N_x turns and reference coil of N_0 turns at short distance on closed iron core. Magnetize core by alternating voltage V_e applied to magnetizing coil N_e. Measure voltages V_x and V_0 using high impedance voltmeter. Then



s 150 $$N_x = N_0\,\frac{V_x}{V_0}$$

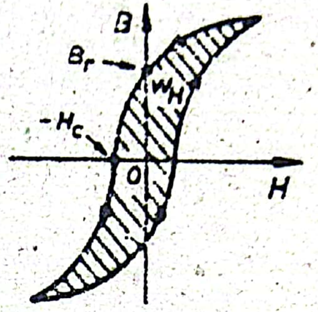
For explanation of symbols see S 20

CamScanner

Hysteresis

Remanent-flux density B_r

A residual magnetism of flux density B_r remains in the iron core, after the external magnetic field strength H has been removed.



Coercive force H_c

The coercive force H_c has to be applied to reduce the flux density B to zero.

Hysteresis work W_H

The energy W_H dissipated during a single cycle of the hysteresis loop is equal to the product of area of the hysteresis loop w_H and core volume V_{Fe}:

s 151 $$W_H = w_H V_{Fe}$$

Hysteresis power P_{VH}

s 152 $$P_{VH} = W_H f = w_H V_{Fe} f$$

Eddy currents

According to the induction law alternating voltages are also induced inside an iron core. Depending on the resistivity of the core iron these voltages cause induction currents called eddy currents. They are kept small by lamination (making up the core of thin metal sheets, which are insulated from each other).

Core losses (iron losses)

Core losses per unit mass p_{Fe}

They are the combined hysteresis and eddy-current losses per unit mass. They are measured at a peak induction $\hat{B}$ = 1 T = 10 kG or 1·5 T = 15 kG and at a frequency f = 50 Hz and are then denoted p_{Fe10} or p_{Fe15} respectively. For values see Z 4.

Total core losses P_{Fe}

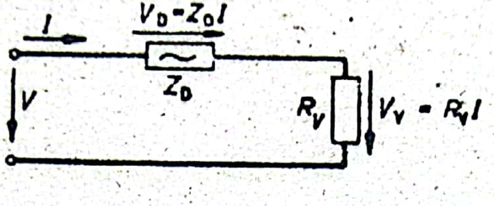
s 153 $$P_{Fe} = p_{Fe10} \left(\frac{\hat{B}}{T} \times \frac{f}{50\ \text{Hz}} \right)^2 m_{Fe} (1 + x)$$

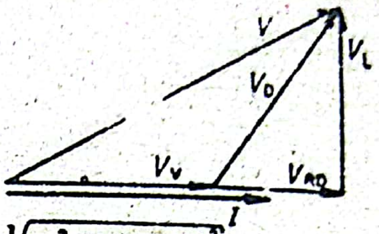
m_{Fe}: mass of core | x: addit. for punchg. ridges etc. (0·1...1·0)

Choke coil

Choke coil used as a dropping impedance

It is used in an ac circuit to reduce the line voltage V down to a value V_V for a resistive load with minimum losses.





s 154 impedance of choke $$Z_D = \sqrt{R_R^2 + (\omega L_R)^2}$$

s 155 impedance of total circuit $$Z = \sqrt{(R_R + R_V)^2 + (\omega L_R)^2}$$

s 156 inductance required $$L_R = \frac{1}{\omega}\sqrt{\left(\frac{V R_V}{V_V}\right)^2 - (R_V + R_R)^2}$$

In a rough calculation of L_R neglect the unknown resistance R_R of the choke. After dimensioning the choke R_R is known, and Z may be determined exactly. Check V_V by

s 157 $$V_V = \frac{V R_V}{Z}$$

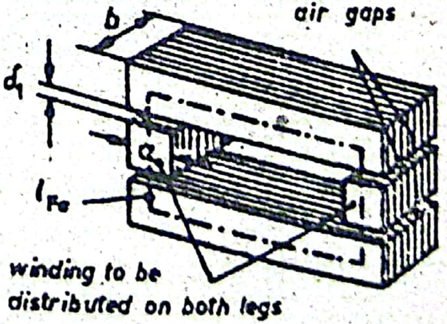
and repeat procedure, if necessary.

Choke of constant inductance without core

Dimension according to S 20. Make preliminary assumptions regarding values r_2/r_1 (toroid coil) or D/u (straight coil). In case of unfavourable results repeat procedure. Determine resistance of choke according to s 85.

Choke coil of constant inductance with iron core

The iron core essentially serves for guiding the magnetic flux and should incorporate as many as possible single air gaps δ_1. These should be filled with insulating layers and should not exceed 1 cm in length. The m.m.f. required to magnetize the core is neglected. Peak values of H and B are used for calculations. The variation of inductance L_R



continued on S 24

continued from S 23

may be expressed in terms of the maximum relative current-depending variation of inductance

s 158 $$g_L = \frac{|L_{R\,tot} - L_R|}{L_R} \; ; \quad \frac{1}{g_L} = \frac{A_{Fe}\,\hat{B}_{Fe}\,\delta}{\hat{H}_{Fe}\,l_{Fe}\,\mu_0\,A_L} + 1$$

If $g_L > g_{L\,requ}$, repeat dimensioning with greater A_{Fe} and smaller $\hat{B}_{Fe}$ at unchanged product $A_{Fe} \times \hat{B}_{Fe}$.

Dimensioning: Given: L_R, f, $g_{L\,requ}$, $V_{L\,eff}$ or I_{eff},

	then the	preliminary dimensions are	final dimensions are
s 159 s 160	effective cross section of core	$A_{Fe}' = \sqrt{K\,I_{eff}\,V_{L\,eff}}$ with $I_{eff} = \frac{V_{L\,eff}}{2\pi f L_R}$	take A_{Fe} from stand. or determine a and b by $A_{Fe} = 0{\cdot}9\,a\,b \approx A_{Fe}'$
s 161	number of turns	$N' = \frac{V_{L\,eff}}{4{\cdot}44\,f\,\hat{B}_{Fe}\,A_{Fe}}$	
s 162	cross section of air gap	$A_L' = ab + 5\,\text{cm}(a+b)$	$[A_L = a\,b + 5(a+b)\delta_1]$
s 163	total length of air gap	$\delta' = \frac{N'^2\,\mu_0\,A_L'}{L_R}$	$\delta \approx \frac{a\,b\,n\,N^2\,\mu_0}{n\,L_R - 5\,N^2\,\mu_0(a+b)}$
s 164	single length of air gap	$\delta_1' = \delta'/n < 1\text{ cm}$	$\delta_1 = \delta/n < 1\text{ cm}$
s 165	diameter of wire	$d' = 2\sqrt{\frac{I}{J'\pi}}$	use next stand. values f. d d_a including insulation
s 166	cross section of winding	$A_W = 1{\cdot}12\,d_a^2\,N$	
	length of limb	l_S to be determined from dimensions of core section and A_W	

Choke coil of current-depending inductance

This type of choke employs an iron core without an air gap. It is used only for special purposes, e.g. as a magnetic amplifier.

K : power coefficient of choke
$\approx 0{\cdot}24\ \text{cm}^4/\text{VA}$ for air-cooled chokes } core section
$\approx 0{\cdot}15\ \text{cm}^4/\text{VA}$ for oil chokes } see S 23
for $\boxed{\square\square}$ core section increase values by 75%
J' : preliminary current density for air-cooled choke $J' = 2\ \text{A/mm}^2$, for oil choke $J' \approx 3 \ldots 4\ \text{A/mm}^2$
$\hat{B}_{Fe}$: core induction (take approx. 1…1·2 T)
$\hat{H}_{Fe}$: field strength in core corr. to $\hat{B}_{Fe}$ to be taken from Z 3 according to material employed
n : number of single air gaps, increase reduces stray flux
R_{Cu} : resistance of winding according to s 26
R_R : resistance of choke includ. core losses ($R_R \approx 1{\cdot}3\,R_{Cu}$)
l_{Fe} : mean length of magnetic path through iron

Transformer

Designation of windings

distinction by

nominal voltages		function in circuit (direction of power transfer)	
winding with higher nominal voltage	winding with lower nominal voltage	input winding	output winding
high-end winding	low-end winding	primary (index 1) winding	secondary (index 2) winding

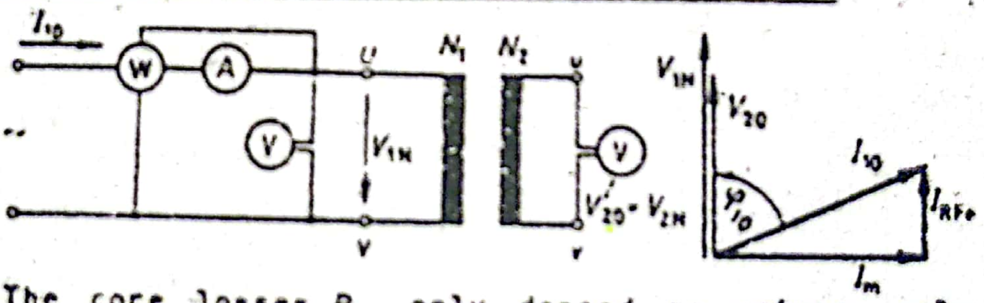
Nominal values (index $_N$)

s 167 rated power $P_{SN} = V_{1N} \times I_{1N} = V_{2N} \times I_{2N}$

s 168 nominal transformation ratio $\ddot{u} = V_{1N} / V_{20} = I_{2N} / I_{1N}$

By the rated secondary voltage V_{2N} we mean the open-circuit secondary voltage ($V_{2N} = V_{20}$), not the one at nominal load.

Core losses P_{Fe} and open-circuit measurements



The core losses P_{Fe} only depend on primary voltage V_1 and frequency f, not on the kind of load.

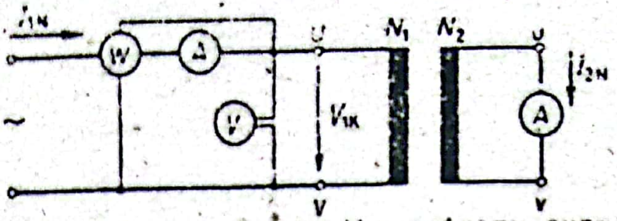
s 169 $P_{10} = P_{Fe}$

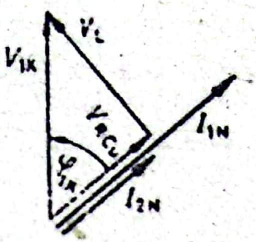
Core losses P_{Fe} and nominal transformation ratio $\ddot{u}$ are determined by open-circuit measurements (see circuit diagram: secondary open, values provided with index 0). The primary current's resistive component I_{RFe} covers the core losses, its reactive component is the magnetizing current I_m. The copper losses are negligibly small. The core losses P_{Fe} are required for calculating operational power dissipation and efficiency.

continued on S 26

continued from S 25

Copper losses P_{Cu} and short-circuit measurements





P_{Cu} depends only on the primary current I_1 and is determined by short-circuit measurements (see circuit diagram, values provided with index K). With the secondary shorted, the primary voltage is adjusted to a value V_{1K}, which causes the rated currents to flow. V_{1K} is so small that $I_{R\,Fe}$ and I_m are negligible. Then the short-circuit primary power P_{1K} is equal to the rated copper losses P_{CuN} of the total transformer at rated currents. P_{1K} is required for calculating operational power dissipation and efficiency.

s 170 $P_{1K} = P_{CuN}$

The values measured are used for calculating the relative short-circuit voltage u_K, which, for bigger transf., is always indicated on the name plate:

s 171 $u_K = 100(V_{1K}/V_{1N})\,\%$

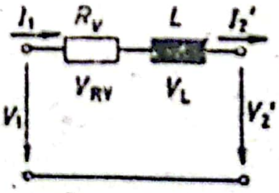
The following quantities may be determined using the vector diagram:

s 172 $R_{Cu} = V_R/I_{1N}$; $L = V_L/\omega I_{1N}$; $\cos\varphi_{1K} = V_R/V_{1K} = \dfrac{P_{CuN}}{u_K\,P_{SN}}$

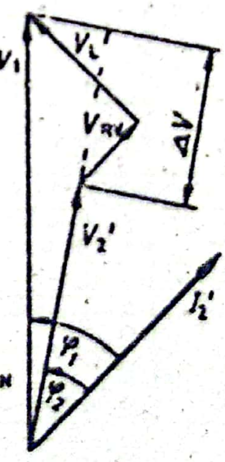
Operating conditions

For calculating the operational secondary voltage V_2 for a given load all secondary quantities are first computed into those of an equiv. transformer having a transf. ratio of $ü = 1$ (index '):

simplified equivalent circuit



simplified vector diagram



s 173 $V_2' = ü\,V_2$; $I_2' = I_2/ü$; $R_2' = ü^2 R_2$

Load-dependent variation ΔV of V_2'

(approximation for $u_K \leq 4\,\%$)

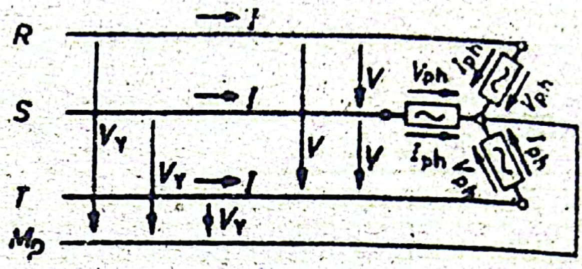
s 174 $\Delta V \approx V_{1K}\,(\cos\varphi_{1K}\cos\varphi_2 + \sin\varphi_{1K}\sin\varphi_2)\,I_2/I_{2N}$

Secondary voltage V_2

s 175 $V_2' \approx V_1 - \Delta V$; $V_2 = V_2'/ü$

Basic connections

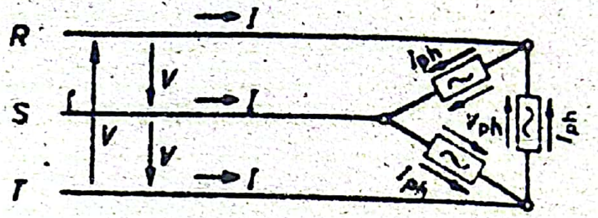
Star



s 176 $V = V_{ph}\sqrt{3}$

s 177 $I = I_{ph}$

Delta



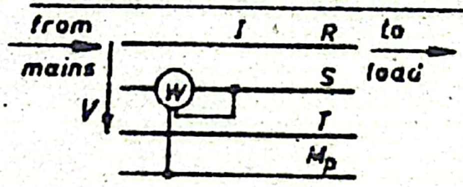
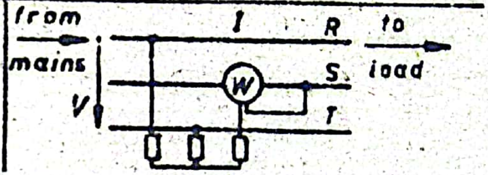
s 178 $V = V_{ph}$

s 179 $I = I_{ph}\sqrt{3}$

Measuring threephase power

Load balanced

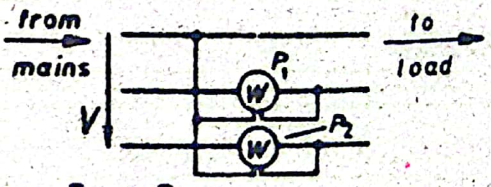
connection

with neutral point (star connected)	without neutral point (delta connected)
	

s 180 total power $P = 3\,P_{w\,str} = \sqrt{3}\,V\,I\cos\varphi$

Load unbalanced (Two wattmeter method)

For general use, thus used with or without neutral point.



s 181 total power $P = P_1 + P_2$

I_{ph} : phase current
I : line current
R,S,T : outer conducter
M_p : neutral conductor
$P_{w\,ph}$: active power of one phase
V_{ph} : phase voltage
V : line voltage

Reactive and active power, power factor
(for symmetrical load)

s 182 reactive power $P_q = \sqrt{3}\, V I \sin\varphi$

s 183 active power $P = \sqrt{3}\, V I \cos\varphi$

s 184 power factor $\cos\varphi = \dfrac{P}{\sqrt{3}\, V I}$

Power factor correction
(for inductive consumers)

General

Adjust to power factor according to current rate, usually $\cos\varphi$ = 0·8...0·9. Adjust large consumers separately and directly and small consumers centrally to main or subdistributors.

Calculating the required capacitor power

Calculate power factor $\cos\varphi$ as above, use wattmeter (see connection in S 27) or a current meter to determine P.

s 185 capacitor power $P_q = (\tan\varphi_1 - \tan\varphi_2)P_w$

s 186 inherent consumption of condenser $P_c \approx 0{\cdot}003\, P_q$

Table (numerical)

$\cos\varphi$	$\tan\varphi$	$\cos\varphi$	$\tan\varphi$	$\cos\varphi$	$\tan\varphi$	$\cos\varphi$	$\tan\varphi$
0·42	2·161	0·62	1·265	0·81	0·724	0·91	0·456
0·44	2·041	0·64	1·201	0·82	0·698	0·92	0·426
0·46	1·930	0·66	1·138	0·83	0·672	0·93	0·395
0·48	1·828	0·68	1·078	0·84	0·646	0·94	0·363
0·50	1·732	0·70	1·020	0·85	0·620	0·95	0·329
0·52	1·643	0·72	0·964	0·86	0·593	0·96	0·292
0·54	1·559	0·74	0·909	0·87	0·567	0·97	0·251
0·56	1·479	0·76	0·855	0·88	0·540	0·98	0·203
0·58	1·405	0·78	0·802	0·89	0·512	0·99	0·142
0·60	1·333	0·80	0·750	0·90	0·484	1	0·000

$\tan\varphi_1$ or $\tan\varphi_2$ can be calculated from the above table, $\cos\varphi_1$ representing the required power factor and $\cos\varphi_2$ the consumer power factor.

Direct-current machine

(motor and generator)

General

s 187	moment constant		$C_M = \frac{p\,z}{2\pi a}$
s 188	rotational source voltage		$V_q = C_M \Phi \omega = 2\pi C_M \Phi n$
s 189	torque		$M = C_M \Phi I_a$
s 190	armature current		$I_a = \frac{\pm(V - V_q)}{R_a}$ *)
s 191	terminal voltage		$V = V_q \pm I_a R_a$ *)
s 192	speed		$n = \frac{V \mp I_a R_a}{2\pi C_M \Phi}$ **)
s 193	internal power		$P_i = M_i \omega = V_q I_a$
s 194	mechanical power supplied	to generator	$P_G = \frac{1}{\eta} V I_{tot}$
s 195		by motor	$P_M = \eta V I_{tot}$

Shunt motor (for circuit diagram see S 30)
Easy starting, speed is fairly independent of load and, within certain limits, easy to regulate.

Series motor (for circuit diagram see S 30)
Easy starting with powerful starting torque. Speed depends greatly on load. When running free may run away.

Compound wound motor (for circuit diagram see S 30)
Operates almost like a shunt motor. Main circuit winding ensures a powerful starting torque.

a : number of armature pairs
p : number of pole pairs
Φ : magnetic flux

z : number of conductors
R_a : armature resistance

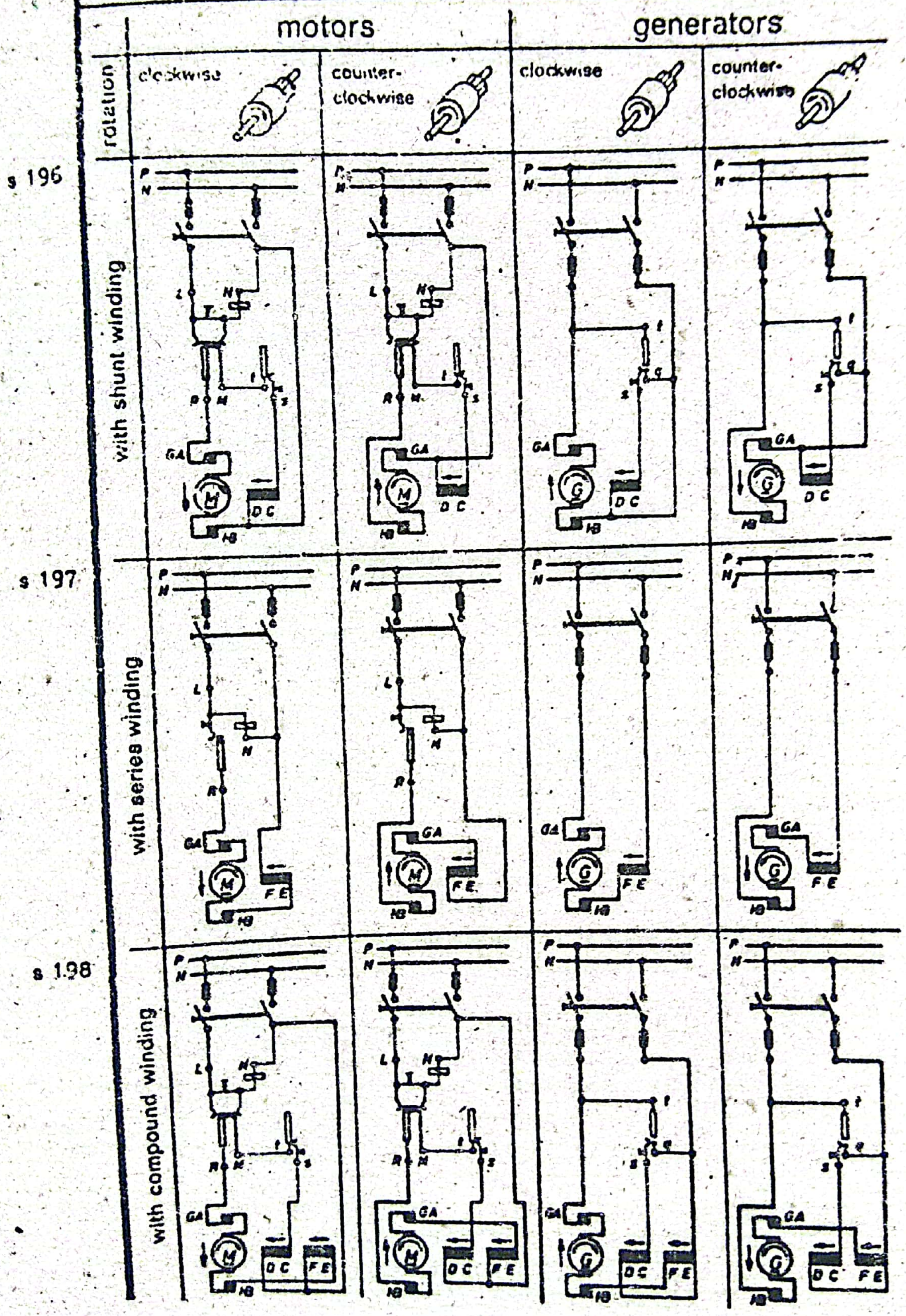
*) + motor
− generator

**) − motor
+ generator

ELECTRICAL ENGINEERING

D.C. machines with commutating poles

S 30



Three-phase motor

Speed

At a given frequency f the speed is determined by the number of pole pairs p.

s 199 speed $n = \frac{f}{p} = \frac{60\,f\,s}{p} \times \frac{1}{\text{min}}$

Switching

Where both terminals of each winding are accessible on the switchboard, the three-phase motor can be connected either in star or in delta.

s 200

phase voltage	
in star	in delta
$V_{ph} = \frac{V}{\sqrt{3}}$	$V_{ph} = V$

A 400/230 volt motor operates with its nominal values of current, torque and power, when connected to

s 201 $V = 230\text{ V}$ in delta, meaning $V_{ph} = V = 230\text{ V}$

s 202 $V = 400\text{ V}$ in star, meaning $V_{ph} = \frac{V}{\sqrt{3}} = \frac{400\text{ V}}{\sqrt{3}} = 230\text{ V}$

Star-delta connection

Higher powered motors usually operate in delta. To avoid excessive inrush currents, particularly in relatively low current networks, the motor is started in star and then switched over into delta. If, for instance, a 400/230 volt motor is connected in star to a 230/135 volt network, it is supplied with only $1/\sqrt{3}$ times its nominal voltage.

Induction motor

The rotating field of the stator causes voltage and current to be induced in the armature winding. Due to slip the rotational speed of the armature is about 3 to 5% lower than that of the rotating field; it remains almost constant under load.

Synchronous motor

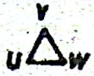
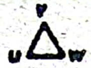
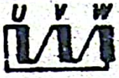
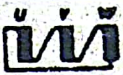
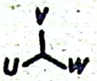
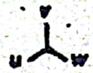
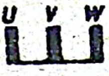
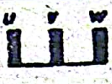
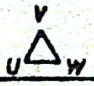
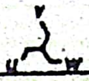
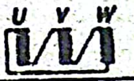
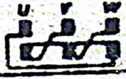
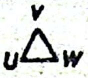
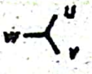
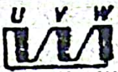
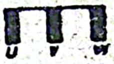
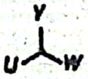
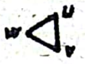
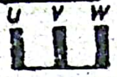
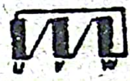
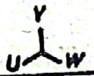
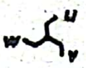
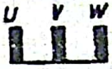
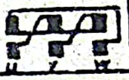
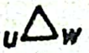
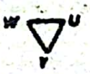
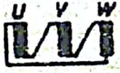
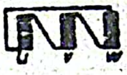
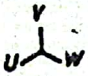
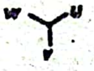
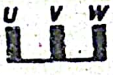
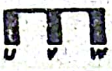
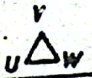
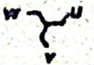
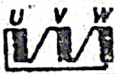
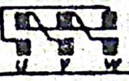
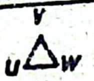
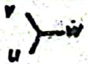
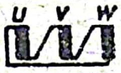
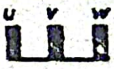
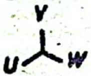
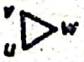
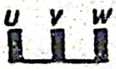
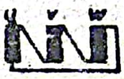
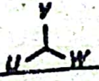
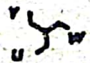
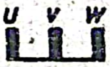
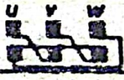
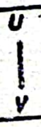
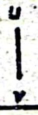
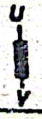
Requires direct current for excitation and is synchronized with the speed of the rotating field by means of an auxiliary squirrel-cage armature. Can be used directly as a generator.

ELECTRICAL ENGINEERING

Transformer switch groups

S 32

Switch groups generally used for transformers

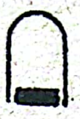
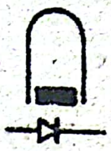
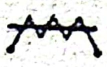
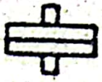
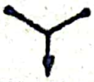
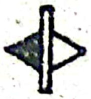
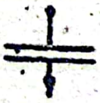
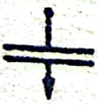
	type		sign		switch diagram		ratio
	key-numb.	switch group	PV	SV	PV	SV	$V_1 : V_2$
	Threephase-output transformers						
s 203	0	D d 0					$\frac{N_1}{N_2}$
s 204		**Y y 0**					$\frac{N_1}{N_2}$
s 205		D z 0					$\frac{2\,N_1}{3\,N_2}$
s 206	5	**D y 5**					$\frac{N_1}{\sqrt{3}\,N_2}$
s 207		**Y d 5**					$\frac{\sqrt{3}\,N_1}{N_2}$
s 208		**Y z 5**					$\frac{2\,N_1}{\sqrt{3}\,N_2}$
s 209	6	D d 6					$\frac{N_1}{N_2}$
s 210		Y y 6					$\frac{N_1}{N_2}$
s 211		D z 6					$\frac{2\,N_1}{3\,N_2}$
s 212	11	D y 11					$\frac{N_1}{\sqrt{3}\,N_2}$
s 213		Y d 11					$\frac{\sqrt{3}\,N_1}{N_2}$
s 214		Y z 11					$\frac{2\,N_1}{\sqrt{3}\,N_2}$
	Single phase-output transformers						
s 215	0	I i 0					$\frac{N_1}{N_2}$

PV: primary voltage
SV: secondary voltage
D d delta
Y y star
– z zig-zag

Key numbers are used to calculate the phase angle (= key number × 30°) between the primary and secondary voltage, e g for Dy5 the phase angle is 5 × 30 = 150°

Note: Use the framed switch groups for preference.

Measuring instruments

	symbol	type	construction	scale	used in metering	
s 216		moving coil	moving coil in steel magnetic field, 2 spiral springs as counter moment and current lead	linear	—	I + V
s 217		moving coil with rectif.		linear	— ~	I + V
s 218		soft iron	moving soft iron, fixed coil, spiral spring as counter mom.	non linear	— ~	I + V
s 219		electro dynamometer	moving coil, fixed coil, 2 spiral springs as counter mom. and curr. lead	square with I and V, linear with P	— ~	I+V+P
s 220		hotwire	hotwire under tension	square	— ~	I + V
s 221		moving magnet	fixed coil revolving magnet	linear	—	I + V
s 222		electrostatic with auxil. voltage	moving capacitor plate, field energized by aux. voltage	irregular	—	V
s 223		electrostatic without auxil. voltage	as above, but field energized by metering voltage	irregular	— ~	V

OPTICS

Photometry

T 1

Basic optical quantities

	quantity	symbol and relation	unit	explanation
t 1	luminous intensity	I_V	candela cd	I_V is a base quantity, see introduction
t 2	solid angle	Ω $\Omega = \frac{A}{r^2}$	steradian 1 sr $= \frac{1\ m^2}{1\ m^2}$	Ω is the ratio of part of the surface of a sphere A to the square of its radius r. The whole solid angle $\Omega_{max} = 4\pi = 12{\cdot}56$ sr.
t 3	luminous flux	Φ_V $\Phi_V = \Omega I_V$	lumen lm = cd sr	Φ_V is the product of solid angle Ω and luminous intensity I_V
t 4	quantity of light	Q_V $Q_V = \Phi_V t$	lumen-second lm s	Q_V is the product of luminous flux Φ_V and time t
t 5	illumination	$E_V = \frac{\Phi_V}{A} = \frac{I_V \cos\alpha}{r^2}$	lux $lx = \frac{lm}{m^2}$	E_V is the ratio of luminous flux Φ_V and illuminated area $A = A_k / \cos\alpha$
t 6	luminance	L_V $= \frac{I_V}{A_1 \cos\varepsilon}$	$\frac{cd}{m^2}$	L_V is the ratio of I_V and projection of emitting surface A_1 perpendicularly to the direction of propagation

Luminous flux consumption for lighting (values see Z 17)

A surface A lit to an illumination E_V will require a luminous flux of

t 7
$$\Phi_V = \frac{A E_V}{\eta}$$

Photometric radiation equivalent

t 8 1 watt = 680 lm for wavelength 0·555 µm

Definition of the base unit "candela"

1 m² of a black body radiating at a temperature of 2043°K has a luminous intensity of 6×10^5 cd

For symbols see T 2

OPTICS

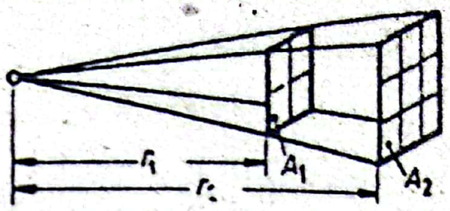
Distance law, Refraction of light

T 2

Optical distance law

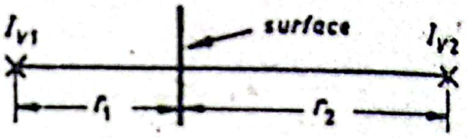
The illumination of a surface is inversely proportional to the square of its distance from the light source:

t 9 $$\frac{E_{v1}}{E_{v2}} = \frac{r_2^2}{r_1^2} = \frac{A_2}{A_1}$$

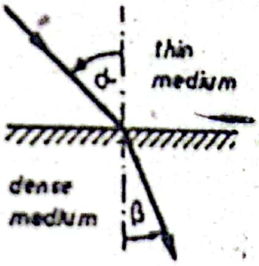


Where two light sources produce equal illumination of a surface, the ratio of the squares of their distances from the surface is equal to the ratio of their luminous intensities:

t 10 $$\frac{I_{v1}}{I_{v2}} = \frac{r_1^2}{r_2^2}$$



Light refraction



t 11 $$\frac{n_b}{n_a} = \frac{\sin\alpha}{\sin\beta}$$

$= $ constant for all angles

t 12 where $\sin\beta \geq \frac{n_a}{n_b}$ { total reflexion occurs

t 13 Refractive index for yellow sodium lighting $\lambda = 589{\cdot}3$ nm

solid matter		fluid matter		gaseous matter	
in relation to atmosphere				in relation to vacuum	
plexiglass	1·49	water	1·33	hydrogen	1·000 139
quartz	1·54	alcohol	1·36	oxygen	1·000 271
crown glass	1·56	glycerine	1·47	atmosphere	1·000 292
diamond	2·41	benzol	1·50	nitrogen	1·000 297

A : illuminated surface | A_1 : radiating surface

α : angle between incoming beam and normal on illuminated surface A

ε : angle between emerging beam and normal on radiating surface A_1

n_a: refractive index for thin medium

n_b: refractive index for dense medium

r : distance between light source and illuminated surface

η : luminous efficacy (see table Z 17)

$c = 0{\cdot}3 \times 10^9$ m/s (velocity of light)

OPTICS

Wavelengths, Mirrors

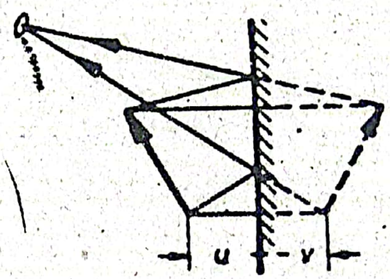
T 3

Wavelengths (in atmosphere)

	type of radiation		wavelength λ	
t 14	Röntgen rays	hard	0·0057...0·08	nm
		soft	0·080 ...2·0	nm
		ultra soft	2·0 ... 37·5	nm
t 15	light rays	ultra violet short	0·014 ...0·18	µm
		ultra violet long	0·18 ...0·36	µm
		violet	0·36 ...0·42	µm
		blue	0·42 ...0·49	µm
		green	0·49 ...0·53	µm
		yellow	0·53 ...0·65	µm
		red	0·65 ...0·81	µm
		ultra red = infra red	0·81 ... 400	µm

t 16 Wavelength $\lambda = c/f$, where c is the velocity of light (see T 2) and f is the frequency of emission.

Mirrors

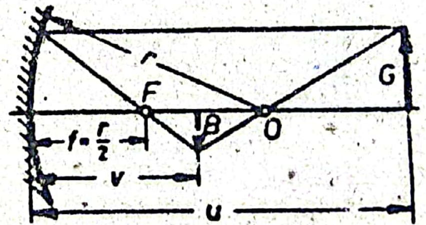


Plane mirrors

The virtual image is true and at the same distance behind the mirror as the object is in front of it:

t 17 $$u = -v$$

Concave mirrors



t 18 $$\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$$

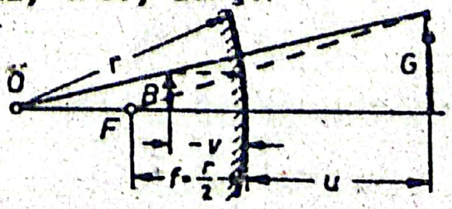
Depending upon the position of object, the image will be real or virtual:

u	v	image
∞	f	at focal point
$>2f$	$f<b<2f$	real, inverted, smaller
$2f$	$2f$	real, inverted, of equal size
$2f>u>f$	$>2f$	real, inverted, larger
f	∞	no image
$<f$	negative	virtual, true, larger

Convex mirrors

Produce only virtual, true and smaller images. Similar to concave mirror where:

$$f = -r/2$$



OPTICS
Lenses

T 4

Lenses

Refraction D of a lens

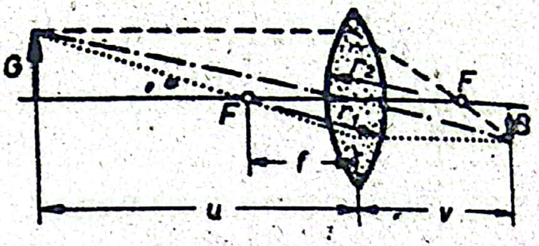
t 19 $D = \frac{1}{f}$; Unit: 1 dpt = 1 dioptrics = $\frac{1}{m}$

Lens equation (thin lenses only)

t 20 $\frac{1}{f} = \frac{1}{v} + \frac{1}{u}$

t 21 $= (n-1)\left(\frac{1}{r_1} + \frac{1}{r_2}\right)$

t 22 $m = \frac{B}{G} = \frac{v}{u}$



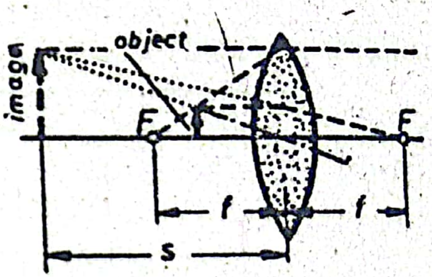
Where two lenses with focal depths f_1 and f_2 are placed immediately one behind the other, the equivalent focal length f, is given by

t 23 $\frac{1}{f} = \frac{1}{f_1} + \frac{1}{f_2}$

Magnifying lens

general	where object is in focus
$m = \frac{s}{f} + 1$	$m = \frac{s}{f}$

t 24

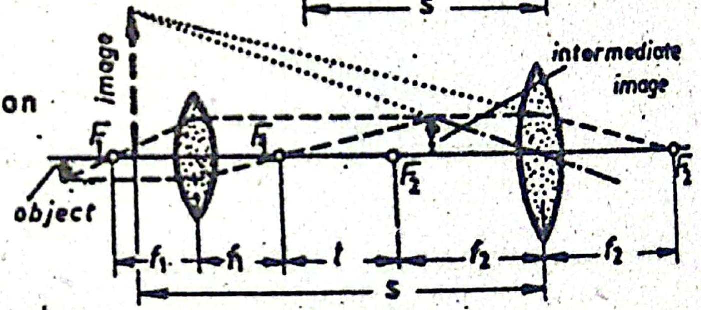


Microscope

total magnification

t 25 $m = \frac{t\ s}{f_1\ f_2}$

t 26 $= m_1 \times m_2$



Macro photography

t 27 camera extension $a = f(m + 1)$

t 28 distance of object $c = \frac{a}{m} = f(1 + \frac{1}{m})$

B : size of image
F : focus
f : focal length
G : size of object
s : range of vision (= 25 cm for normal vision)

n : refractive index (see T2)
r : radius of curvature
t : optical length of tube
m : magnification factor

CHEMISTRY
Elements

element	symbol	atomic mass in u	element	symbol	atomic mass in u
aluminium	Al	26·9815	neodymium	Nd	144·240
antimony	Sb	121·75	neon	Ne	20·183
argon	Ar	39·948	nickel	Ni	58·71
arsenic	As	74·9216	niobium	Nb	92·906
barium	Ba	137·34	nitrogen	N	14·0067
beryllium	Be	9·0122	osmium	Os	190·2
bismuth	Bi	208·980	oxygen	O	15·9994
boron	B	10·811	palladium	Pd	106·4
bromine	Br	79·909	phosphorus	P	30·9738
cadmium	Cd	112·40	platinum	Pt	195·2
caesium	Cs	132·905	potassium	K	39·102
calcium	Ca	40·08	praseodymium	Pr	140·907
carbon	C	12·0112	radium	Ra	226·04
cerium	Ce	140·12	rhodium	Rh	102·905
chlorine	Cl	35·453	rubidium	Rb	85·47
chromium	Cr	51·996	ruthenium	Ru	101·07
cobalt	Co	58·9332	samarium	Sm	150·35
copper	Cu	63·54	scandium	Sc	44·956
erbium	Er	167·26	selenium	Se	78·96
fluorine	F	18·9984	silicon	Si	28·086
gadolinium	Gd	157·25	silver	Ag	107·870
gallium	Ga	69·72	sodium	Na	22·9898
germanium	Ge	72·59	strontium	Sr	87·62
gold	Au	196·967	sulphur	S	32·064
helium	He	4·0026	tantalum	Ta	180·948
hydrogen	H	1·008	tellurium	Te	127·6
indium	In	114·82	thallium	Tl	204·37
iodine	I	126·9044	thorium	Th	232·038
iridium	Ir	192·2	thulium	Tm	168·934
iron	Fe	55·847	tin	Sn	118·69
krypton	Kr	83·80	titanium	Ti	47·90
lanthanum	La	138·91	tungsten	W	183·85
lead	Pb	207·19	uranium	U	238·03
lithium	Li	6·939	vanadium	V	50·942
magnesium	Mg	24·312	xenon	Xe	131·30
manganese	Mn	54·9381	yttrium	Y	88·905
mercury	Hg	200·59	zinc	Zn	65·37
molybdenum	Mo	95·94	zirconium	Zr	91·22

u : Atomic unit of mass (1 u is one twelfth of the mass of an atom of isotope C^{12})

U 2 CHEMISTRY

Acids, Bases, Equations

pH values

The negative log of the hydrogen-ion-concentration c_{H^+} indicates its pH value:

$$pH = -\lg c_{H^+}$$

u 1

c_{H^+}	1	10^{-1}	10^{-2}	. . .	10^{-7}	. . .	10^{-12}	10^{-13}	10^{-14}
pH	0	1	2	. . .	7	. . .	12	13	14
	← acid →				neutral	← alkaline →			

Establishing pH values by using suitable indicators.

Reagents

reagent	indicator	colouration	
acids	blue litmus paper red phenolphthalein yellow methylorange	red colourless red	u 2
bases	red litmus paper colourless phenolphthalein red methylorange	blue red yellow	u 3
ozone	potassium-iodide starch paper	blue-black	u 4
H_2S	lead iodide paper	brown-black	u 5
ammonia solution	hydrochloric acid	white fumes	u 6
carbonic acid	calcium hydroxide	sediment	u 7

Preparation of chemicals

to prepare	use equation	
ammonia	$CO(NH_2)_2 + H_2O \rightarrow 2\,NH_3 + CO_2$	u 8
ammonium chloride	$NH_4OH + HCl \rightarrow NH_4Cl + H_2O$	u 9
ammonium hydroxide	$NH_3 + H_2O \rightarrow NH_4OH$	u 10
cadmium sulphide	$CdSO_4 + H_2S \rightarrow CdS + H_2SO_4$	u 11
carbon dioyide	$CaCO_3 + 2\,HCl \rightarrow CO_2 + CaCl_2 + H_2O$	u 12
chlorine	$CaOCl_2 + 2\,HCl \rightarrow Cl_2 + CaCl_2 + H_2O$	u 13
hydrogen	$H_2SO_4 + Zn \rightarrow H_2 + ZnSO_4$	u 14
hydrogen sulphide	$FeS + 2\,HCl \rightarrow H_2S + FeCl_2$	u 15
lead sulphide	$Pb(NO_3)_2 + H_2S \rightarrow PbS + 2\,HNO_3$	u 16
oxygen	$2\,KClO_3 \rightarrow 3\,O_2 + 2\,KCl$	u 17
sodium hydroxide	$Na_2O + H_2O \rightarrow 2\,NaOH$	u 18
zinc sulphide	$ZnSO_4 + H_2S \rightarrow ZnS + H_2SO_4$	u 19

CHEMISTRY

Chemicals

U 3

Chemical terms

trade name	chemical name	chemical formula
acetone	acetone	$(CH_3)_2 \cdot CO$
acetylene	acetylene	C_2H_2
ammonia	ammonia	NH_3
ammonium (hydrox. of)	ammonium hydroxide	NH_4OH
aniline	aniline	$C_6H_5 \cdot NH_2$
bauxite	hydrated aluminum oxides	$Al_2O_3 \cdot 2 H_2O$
bleaching powder	calcium hypochlorite	$CaCl(OCl)$
blue vitriol	copper sulphate	$CuSO_4 \cdot 5 H_2O$
borax	sodium tetraborate	$Na_2B_4O_7 \cdot 10 H_2O$
butter of zinc	zinc chloride	$ZnCl_2 \cdot 3 H_2O$
cadmium sulphate	cadmium sulphate	$CdSO_4$
calcium chloride	calcium chloride	$CaCl_2$
carbide	calcium carbide	CaC_2
carbolic acid	phenol	C_6H_5OH
carbon dioxide	carbon dioxide	CO_2
carborundum	silicon carbide	SiC
caustic potash	potassium hydroxide	KOH
caustic soda	sodium hydroxide	$NaOH$
chalk	calcium carbonate	$CaCO_3$
cinnabar	mercuric sulphide	HgS
ether	di-ethyl ether	$(C_2H_5)_2O$
fixing salt or hypo	sodium thiosulphate	$Na_2S_2O_3 \cdot 5 H_2O$
glauber's salt	sodium sulphate	$Na_2SO_4 \cdot 10 H_2O$
glycerine or glycerol	glycerine	$C_3H_5(OH)_3$
graphite	crystaline carbon	C
green vitriol	ferrous sulphate	$FeSO_4 \cdot 7 H_2O$
gypsum	calcium sulphate	$CaSO_4 \cdot 2 H_2O$
heating gas	propane	C_3H_8
hydrochloric acid	hydrochloric acid	HCl
hydrofluoric acid	hydrofluoric acid	HF
hydrogen sulphide	hydrogen sulphide	H_2S
iron chloride	ferrous chloride	$FeCl_2 \cdot 4 H_2O$
iron sulphide	ferrous sulphide	FeS
laughing gas	nitrous oxide	N_2O
lead sulphide	lead sulphide	PbS
limestone	calcium carbonate	$CaCO_3$

continued on U 4

U 4

CHEMISTRY

Chemicals

continued from U 3

trade name	chemical name	chemical formula
limestone	calcium carbonate	$CaCO_3$
magnesia	magnesium oxide	MgO
marsh gas	methane	CH_4
minium or red lead	plumbate	$2\,PbO \cdot PbO_2$
nitric acid	nitric acid	HNO_3
phosphoric acid	ortho phosphoric acid	H_3PO_4
potash	potassium carbonate	K_2CO_3
potassium bromide	potassium bromide	KBr
potassium chlorate	potassium chlorate	$KClO_3$
potassium chloride	potassium chloride	KCl
potassium chromate	potassium chromate	K_2CrO_4
potassium cyanide	potassium cyanide	KCN
potassium dichromate	potassium dichromate	$K_2Cr_2O_7$
potassium iodide	potassium iodide	KI
prussic acid	hydrogen cyanide	HCN
pyrolusite	manganese dioxide	MnO_2
quicklime	calcium monoxide	CaO
red prussiate of pot.	potassium ferrocyan.	$K_3Fe(CN)_6$
salammoniac	ammonium chloride	NH_4Cl
silver bromide	silver bromide	$AgBr$
silver nitrate	silver nitrate	$AgNO_3$
slaked lime	calcium hydroxide	$Ca(OH)_2$
soda ash	hydrated sodium carb.	$Na_2CO_3 \cdot 10\,H_2O$
sodium monoxide	sodium oxide	Na_2O
soot	amorphous carbon	C
stannous chloride	stannous chloride	$SnCl_2 \cdot 2\,H_2O$
sulphuric acid	sulphuric acid	H_2SO_4
table salt	sodium chloride	$NaCl$
tinstone, tin putty	stannic oxide	SnO_2
trilene	trichlorethylene	C_2HCl_3
urea	urea	$CO(NH_2)_2$
water	water	H_2O
white lead	basic lead carbonate	$2\,PbCO_3 \cdot Pb(OH)_2$
white vitriol	zinc sulphate	$ZnSO_4 \cdot 7\,H_2O$
yellow pruss. of pot.	potass. ferrocyanide	$K_4Fe(CN)_6 \cdot 3H_2O$
zinc blende	zinc sulphide	ZnS
zinc or chinese white	zinc oxide	ZnO

TABLES

Electrical properties

Electrical specific resistance ρ and specific conductance γ of conductors at 20°C

material	ρ $\frac{\Omega\,mm^2}{m}$	γ $\frac{m}{\Omega\,mm^2}$	material	ρ $\frac{\Omega\,mm^2}{m}$	γ $\frac{m}{\Omega\,mm^2}$
aluminium	0·0278	36	iron (pure)	0·10	10
antimony	0·417	2·4	lead	0·208	4·8
brass-58%Cu	0·059	17	magnesium	0·0435	23
brass-63%Cu	0·071	14	manganese	0·423	2·37
cadmium	0·076	13·1	mercury	0·941	1·063
carbon	40	0·025	mild steel	0·13	7·7
cast iron	1	1	nickel	0·087	11·5
chromium-Ni-Fe	0·10	10	nickeline	0·5	2·0
constantan	0·48	2·08	platinum	0·111	9
copper	0·0172	58	silver	0·016	62·5
German silver	0·369	2·71	tin	0·12	8·3
gold	0·0222	45	tungsten	0·059	17
graphite	8·00	0·125	zinc	0·061	16·5

Electrical resistance ρ of insulators

material	ρ Ω cm	material	ρ Ω cm
bakelite	10^{14}	plexiglass	10^{15}
glass	10^{15}	polystyrene	10^{18}
marble	10^{10}	porcelain	10^{14}
mica	10^{17}	pressed amber	10^{18}
paraffin oil	10^{18}	vulcanite	10^{16}
paraffin wax (pure)	10^{18}	water, distilled	10^{7}

Electric temperature coefficient α_{20} at 20°C

material	α_{20} 1/K or 1/°C	material	α_{20} 1/K or 1/°C
aluminium	+ 0·00390	mercury	+ 0·00090
brass	+ 0·00150	mild steel	+ 0·00660
carbon	− 0·00030	nickel	+ 0·00400
constantan	− 0·00003	nickeline	+ 0·00023
copper	+ 0·00380	platinum	+ 0·00390
German silver	+ 0·00070	silver	+ 0·00377
graphite	− 0·00020	tin	+ 0·00420
manganese	± 0·00001	zinc	+ 0·00370

Z 2 TABLES

Electrical properties

Dielectric constant ε_r

insulant	ε_r	insulant	ε_r
araldite	3·6	paraffin oil	2·2
atmosphere	1	paraffin wax	2·2
bakelite	3·6	petroleum	2·2
casting compound	2·5	phenolic resin	8
castor oil	4·7	plexiglass	3·2
ebonite	2·5	polystyrene	3
glass	5	porcelain	4·4
guttapercha	4	pressed board	4
hard paper (lamin.)	4·5	quartz	4·5
insulation of high voltage cables	4·2	shellac	3·5
insulation of telephone cables	1·5	slate	4
marble	8	soft rubber	2·5
mica	6	steatite	6
micanite	5	sulphur	3·5
nylon	5	teflon	2
oil paper	4	transf. oil mineral	2·2
olive oil	3	transf. oil vegetab.	2·5
paper	2·3	turpentine	2·2
paper, impregnated	5	vulcanised fibres	2·5
		vulcanite	4
		water	80

Electro-motive series

(potential difference with respect to hydrogen electrode)

material	U volt	material	U volt
potassium	−2·93	cadmium	−0·40
calcium	−2·87	cobalt	−0·28
sodium	−2·71	nickel	−0·23
magnesium	−2·37	tin	−0·14
beryllium	−1·85	lead	−0·13
aluminium	−1·66	hydrogen	0·00
manganese	−1·19	copper	+0·34
zinc	−0·76	silver	+0·80
chromium	−0·74	mercury	+0·85
tungsten	−0·58	platinum	+1·20
iron	−0·41	gold	+1·50

TABLES

Magnetic properties

Z 3

Magnetic field strength *H* and relative permeability μ_r as a function of induction *B*

induction *B*		cast iron		steel casting and dynamo sheet steel $p_{Fe10} = 3{\cdot}6\ \frac{W}{kg}$		alloyed dynamo sheet steel $p_{Fe10} = 1{\cdot}3\ \frac{W}{kg}$	
		H	μ_r	*H*	μ_r	*H*	μ_r
$T = \frac{V\,s}{m^2}$ (tesla)	G (gauss)	A/m	-	A/m	-	A/m	-
0·1	1 000	440	181	30	2 650	8·5	9 390
0·2	2 000	740	215	60	2 650	25	6 350
0·3	3 000	980	243	80	2 980	40	5 970
0·4	4 000	1 250	254	100	4 180	65	4 900
0·5	5 000	1 650	241	120	3 310	90	4 420
0·6	6 000	2 100	227	140	3 410	125	3 810
0·7	7 000	3 600	154	170	3 280	170	3 280
0·8	8 000	5 300	120	190	3 350	220	2 900
0·9	9 000	7 400	97	230	3 110	280	2 550
1·0	10 000	10 300	77	295	2 690	355	2 240
1·1	11 000	14 000	63	370	2 360	460	1 900
1·2	12 000	19 500	49	520	1 830	660	1 445
1·3	13 000	29 000	36	750	1 380	820	1 260
1·4	14 000	42 000	26	1 250	890	2 250	495
1·5	15 000	65 000	18	2 000	600	4 500	265
1·6	16 000			3 500	363	8 500	150
1·7	17 000			7 900	171	13 100	103
1·8	18 000			12 000	119	21 500	67
1·9	19 000			19 100	79	39 000	39
2·0	20 000			30 500	52	115 000	14
2·1	21 000			50 700	33		
2·2	22 000			130 000	13		
2·3	23 000			218 000	4		

——— practical limit

Z 4

TABLES

Magnetic properties

Dynamo sheet properties

type			mild sheet steel	alloy sheet steel			
				low	medium	high	
class of sheet			I 3·6	II 3·0	III 2·3	IV 1·5	IV 1·3
panel size mm x mm			1000 x 2000				750x 1500
thickness mm			0·5				0·35
density kg/dm³			7·8	7·75	7·65	7·6	
core losses per unit mass at f = 50Hz W/kg (max.)	p_{Fe10}		3·6	3·0	2·3	1·5	1·3
	p_{Fe15}		8·6	7·2	5·6	3·7	3·3
in-duction (min.)	B_{25}	V s/m² gauss	1·53 15 300	1·50 15 000	1·47 14 700	1·43 14 300	
	B_{50}	V s/m² gauss	1·63 16 300	1·60 16 000	1·57 15 700	1·55 15 500	
	B_{100}	V s/m² gauss	1·73 17 300	1·71 17 100	1·69 16 900	1·65 16 500	
	B_{300}	V s/m² gauss	1·98 19 800	1·95 19 500	1·93 19 300	1·85 18 500	

Explanations

B_{25} = 1·53 Vs/m² indicates that a minimum induction of 1·53 V s/m² (or 15 300 gauss) is reached with a field strength of 25 A/cm. Thus a flux length of e.g. 5 cm requires a circulation of 5 x 25 A = 125 A.

p_{Fe10}	describes the core losses per unit mass at f = 50 Hz and an induction of	10 000 G = 1·0 V s/m²
p_{Fe15}		15 000 G = 1·5 V s/m²

TABLES

Properties of solids and liquids

Z 5

Conditions, for which properties listed below are valid

Density of solids and fluids: Ambient temperature 15°C

Boiling point in degrees centigrade: Ambient pressure 101·32 kN/m^2(= 760 torr). Parentheses indicate sublimation, i.e. direct transition from the gaseous to the solid state.

Specific heat: Mean values for the temperature range between 0°C and 100°C.

substance	density ρ	melting point	boiling point	thermal conductivity λ	specific heat c
	kg/dm³	°C	°C	W/(m K)[1]	kJ/(kg K)[2]
acetic acid	1·08	16·8	118	·	·
acetone	0·79[3]	·	56·1	·	·
agate	~2·6	~1600	~2600	10·89	0·80
alcohol	0·79	− 130	78·4	0·17...0·2	2·43
alcohol 95%	0·82[3]	− 90	78	0·16	·
alumin. bronze	7·7	1040	~2300	127·9	0·436
aluminium cast	2·6	658	~2200	209·4	0·904
aluminium roll.	2·7	658	~2200	209·4	0·904
amber	1·0	~300	·		
antimony	6·67	630	1440	22·53	0·209
arsenic	5·72	815	[633]	·	0·348
artific. wool	1·5	·	·	·	1·357
asbestos	~2·5	·	·	0·17	0·817
barium	3·6	700	1537	·	0·29
barytes	4·5	1580	·	·	0·46
benzene	0·89	5·4	80	0·137	1·80
benzine	0·7	− 150	50...200	0·16	~2·1
beryllium	1·85	1279	·	167·5	1·880
bismuth	9·8	271	1480	10·5	0·13
boiler scale	~2·5	~1200	~2800	1·2...3·5	0·80
borax	1·72	741	·	·	0·997
brass, cast	8·4...8·7	900...980	~2300	81...105	0·385
brass, rolled	8·5...8·6	900...980	~2300	87...116	0·385
brick	1·4...1·6	·	·	0·8	0·92
bromine	3·14	− 7·3	63	·	·
bronze	~8·0	900	2300	116...186	0·360
brown iron ore	~3·5	1565	·	·	0·733

[1] 1 W/(m K) = 0·8598 kcal/(h m °C)

[2] 1 kJ/(kg K) = 0·2388 kcal/(kg °C)

[3] at t = 20 °C

CamScanner

Z 6

TABLES

Properties of solids and liquids

substance	density ρ	melting point	boiling point	thermal conductivity λ	specific heat c
	kg/dm³	°C	°C	W/(m K)[1]	kJ/(kg K)[2]
cadmium	8·64	321	778	92·1	0·235
calcium	1·55	800	851	·	0·63
carbon	3·51	~3600	[3540]	8·4	0·854
cast iron	7·25	~1200	2500	48·8	0·532
cast steel	7·8	~1350	·	52·3	0·503
cerium	6·77	630			
chalk	1·8...2·6	·	·	0·9...1·2	0·84
charcoal	0·3...0·5	·	[3540]	0·08	0·84
chloroform	1·53	−70	61	·	·
chromium	6·7	~1800	2200	·	0·452
clay	1·8...2·6	~1600	2980	0·84	0·92
cobalt	8·8	1490	3168	69·8	0·436
coke	1·4	·	·	0·184	0·84
colza oil	0·91 [3]	−3·5	300	0·17	1·97
concrete reinf.	2·4	·	·	0·8...1·7	0·88
constantan	8·89	~1600	~2400	23·3	0·410
copper, cast	8·8	1083	2310	372·2	0·394
copper, rolled	8·9	1083	2310	372·2	0·394
cork	0·2...0·3	·	·	0·30	2·05
diamond	3·5	·	[3540]	8·4	0·3333
diesel oil	0·88	−5	175	0·13	·
dripping, beef	0·9...1·0	40...50	350	·	0·88
duralium	2·8	650	2000	129·1	0·92
ebonite	1·2...1·8	·	·	0·17	·
electron	1·8	650	1500	162·8	1·00
emery	4·0	2200	3000	11·6	0·96
ether	0·73 [3]	−117	35	0·14	2·26
fats	0·93	30...175	~300	0·21	0·63...0·75
fire brick	1·8...2·2	~2000	2900	0·47	0·88
gas oil	0·86	−30	200..350	0·15	·
German silver	8·4...8·7	~1050	·	29·1	0·398
glass, window	~2·5	~700	·	0·6...1·0	0·84
glass-wool	0·1...0·2	·	·	0·03...0·07	0·84
glycerine	1·27 [4]	−20	290	0·29	2·43
gold	19·33	1064	2610	308·2	0·130
graphite	~2·1	·	[3540]	5·02	0·825

[1] 1 W/(m K) = 0·8598 kcal/(h m °C)
[2] 1 kJ/(kg K) = 0·2388 kcal/(kg °C)

[3] at t = 20 °C
[4] at t = 0 °C

TABLES

Properties of solids and liquids

substance	density ρ	melting point	boiling point	thermal conductivity λ	specific heat c
	kg/dm³	°C	°C	W/(m K) [1]	kJ/(kg K) [2]
heating oil	0·92 [1]	− 5	175...350	0·12	·
high speed stl.	8·4...9·0	~1650	2600	25·6	0·498
hydrochlor acid 10%	1·05	− 14	102	0·50	3·14
40%	1·20	·	·	·	·
hydr. fluoride	0·99	− 92·5	19·5	·	·
ice	0·9	0	100	1·7	2·09
ingot iron	7·85	~1400	2500	46·5	0·461
iodine	4·95	113·5	[184]	·	0·218
iridium	22·4	2450	4800	59·3	0·134
iron, cast	7·25	~1200	42·0	48·8	0·532
iron, forged	7·8	~1200	·	46...58	0·461
iron-oxide	5·1	1565	·	0·58	0·67
iron, pure	7·86	1530	~3000	46...58	0·456
lead	11·34	327	1525	35·0	0·130
leather	0·9...1·0	·	·	0·17	1·495
limestone	1·8...2·8	·	·	0·15...0·2	0·909
linseed oil	0·94 [3]	− 20	316	0·15	·
lithium	0·53	186	1336	301·2	0·360
machine oil	0·91	− 5	380...400	0·126	1·68
magnesia	3·2...3·6	·	·	·	·
magnesium	1·74	650	1120	157·0	1·05
" , alloy	1·8	650	1500	70...145	1·01
manganese	7·3	1260	1900	·	0·46
marble	2·0...2·8	1290	2870	2·1...3·5	0·88
mercury	13·6	− 38·9	357	8·4	0·138
methyl alcohol	0·8	− 98	66	·	2·51
mica	~3·0	~1300	·	0·35	0·88
molybdenum	10·2	~2500	3560	·	0·272
nickel	8·8	1452	2400	52·3	0·461
nitric acid	1·56 [4]	− 1·3	86	0·54	2·722
oil of resin	0·94 [3]	− 20	150...300	0·15	·
oil of turpent.	0·87	− 10	160	0·10	1·80
osmium	22·48	~2500	5300	·	0·130
oxide of chrom.	5·21	2200	·	0·42	0·75
palladium	11·5	1549	2200	70·9	0·247
paper	0·7...1·1	·	·	·	1·336

---

[1] 1 W/(m K) = 0·8598 kcal/(h m °C)

[2] 1 kJ/(kg K) = 0·2388 kcal/(kg °C)

[3] at t = 20 °C

[4] at t = 0 °C

Z 8

TABLES

Properties of solids and liquids

substance	density ρ	melting point	boiling point	thermal conductivity λ	specific heat c
	kg/dm^3	°C	°C	W/(m K) 1)	kJ/(kg K) 2)
paraffin	0·9	52	300	0·21	3·27
peat	0·64	·	·	0·06...0·12	1·88
perchlor ethyl.	1·62	− 20	119	·	0·905
petroleum	0·80	− 70	150...300	0·159	2·09
" ether	0·67	− 160	40...70	0·14	1·76
phosphorbronze	8·8	900	·	105...116	0·364
phosphorus	1·83	44·2	287·3	·	0·80
pig iron, white	7·0...7·8	1560	2500	52·3	0·54
pinchbeck	8·65	900	2300	93...116	0·381
pitch	1·08	·	·		
pit coal	1·2...1·5	·	·	0·16	1·30
platinum	21·4	1764	3800	69·8	0·130
porcelain	2·2...2·5	1670	·	0·8...1·0	0·92
potassium	0·86	63	762·2	·	0·080
prussic acid	0·7	− 15	27	·	·
quartz	~2·6	~1550	2590	1·09	0·80
radium	5	700	·	·	·
red lead	8·6...9·1	900	·	0·7	0·25
red metal	8·8	950	2300	127·9	0·381
rhenium	21·4	3170	·	·	0·147
rhodium	12·3	1960	2500	88·4	0·243
rosin	1·07	100...130	·	0·316	1·88
rubber, raw	0·95	125	·	0·2...0·35	·
rubidium	1·52	39	696		0·34
sand, dry	1·2...1·6	~1550	2600	0·33	0·80
sandstone	1·9...2·6	~1500	2600	1·3...1·7	0·92
selenium	4·3...4·8	220	690	·	0·352
silicon	2·34	~1415	2400	·	0·80
" , carbide	3·12	·	·	15·2	0·67
silver	10·5	960	2000	418·7	0·235
slate	2·6...2·7	~2000	·	0·42	0·758
snow	0·1	0	·	·	·
sodium	0·98	97·5	880	133·8	1·256
soot	1·6...1·7	·	[3540]	0·07	0·84
steatite	2·6...2·7	1650	·	2·7...2·8	1·05
steel	7·85	~1350	2500	47...58	0·46

1) 1 W/(m K) = 0·8598 kcal/(h m °C)

2) 1 kJ/(kg K) = 0·2388 kcal/(kg °C)

TABLES

Properties of solids and liquids

Z 9

substance	density ρ	melting point	boiling point	thermal conductivity λ	specific heat c
	$\mathrm{kg/dm^3}$	°C	°C	W/(m K) [1]	kJ/(kg K) [2]
sulphur, cryst.	1·96	113	445	0·27	0·75
sulph.acid conc.	1·84	10…0	338	0·5	1·38
sulph.acid 50%	1·40	·	·	·	·
sulphurus acid	1·49 [5]	− 73	− 10	·	1·34
tantalum	16·6	3030	·	73·3	0·138
tar	1·2	− 15	300	0·19	·
tellurium	6·25	455	1390	·	0·201
thorium	11·3	1845	·	·	0·113
timber, alder	0·4…0·7	·	·	~0·152	1·42
" , ash	0·6…0·9	·	··	0·3…0·5	1·59
" , birch	0·5…0·8	·	·	0·142	1·88
" , larch	0·5…0·8	·	·	0·1	1·30
" , longl. p.	0·84	·	·	·	1·38
" , marle	0·6…0·9	·	·	0·3…0·5	1·59
" , oak	0·7…1·0	·	·	0·21	2·39
" , pitchpine	0·5…0·8	·	·	0·16	1·30
" , pockwood	1·28	·	·	0·19	2·51
" , red bch.	0·7…0·9	·	·	0·143	1·34
" , red pine	0·5…0·8	·	·	0·1…0·2	1·47
" , white b.	0·6…0·8	·	·	0·143	1·34
" , white p.	0·4…0·7	·	·	0·1…0·2	1·47
tin, cast	7·2	232	2200	64·0	0·25
tin, rolled	7·3…7·5	232	2200	64·0	0·25
titanium	4·5	1800	·	·	0·611
toluene	0·88	− 94·5	110	0·14	1·59
trichlor-ethyl.	1·47	− 86	87	0·16	1·30
tungsten	19·1	~3350	4850	11·9	0·155
uranium	18·7	1850	·	·	0·117
vanadium	5·6	1715	·	·	0·50
water	1 at 4°	0	100	0·58	4·183
wax	0·96	64	65…70	0·084	3·43
welding iron	7·8	1600	2500	54·7	0·515
white metal	7·5…10	300…400	2100	35…70	0·147
zinc, cast	6·86	419	920	110·5	0·38
zinc, die-cast	6·8	393	~1000	139·6	0·38
zinc, rolled	7·15	419	920	105·8	0·38

[1] 1 W/(m K) = 0·8598 kcal/(h m °C)

[2] 1 kJ/(kg K) = 0·2388 kcal/(kg °C)

[5] at t = −20 °C

Z 10

TABLES

Properties of gases

Conditions,
for which properties listed below are valid

Density	at t = 15°C	at p = 101·32 kN/m² = 1·0132 bar = 760 torr
Melting and boiling point		
Thermal conductivity	at t = 20°C	
Specific heat		

substance	density ϱ	melting point	boiling point	thermal conductivity λ	specific heat c_p	specific heat c_v
	kg/m³	°C	°C	W/(m K)	kJ/(kg K)[1]	kJ/(kg K)[1]
acetylene	1·18	− 84	− 81	0·017017	1·67	1·34
air, atmosphere	1·293	−220	−195	0·0221	1·00	0·71
ammonia	0·77	− 78·3	− 33·7	0·01989	2·22	1·72
argon	1·78	−190	−186	0·015912	0·54	0·33
blast furn. gas	1·28	−210	−170	0·01989	1·05	0·75
butan, iso	2·67	−145	− 10	·	·	·
butan, n-	2·70	−135	1	·	·	·
carbon di-oxide	1·96	− 57	− 78·5	0·01326	0·88	0·63
carbon disulph.	3·41	−112	46	0·006188	0·67	0·54
carbon monoxide	1·25	−211	−190	0·020995	1·05	0·75
chlorine	3·22	−100	− 34	0·014365	0·50	0·29
coal gas	0·55	−230	−210	0·05525	2·14	1·55
ethylene	1·26	−169	−102	0·034034	1·55	1·21
helium	0·18	−272	−268·8	0·143	5·23	3·18
hydrochlor acid	1·64	−114	− 85	·	0·80	0·59
hydrogen	0·09	−258	−253	0·161993	14·28	10·14
hydrogen sulph.	1·54	− 83	− 60·3	·	·	·
krypton	3·70	−157	−152	0·00878	0·25	0·17
methane	0·72	−184	−164	0·028067	2·22	1·72
neon	0·90	−249	−246	0·043758	1·05	0·63
nitrogen	1·25	−210·5	−195·7	0·0221	1·05	0·75
oxigen	1·43	−219	−183	0·022321	0·92	0·67
ozone	2·14	−251	−112	·	·	·
producer gas	1·22	−210	−170	0·01989	1·05	0·75
propane	2·02	−190	− 45	·	·	·
sulphur dioxide	2·93	− 73	− 10	0·015912	0·63	0·50
water vapour[2]	0·81	0	100	0·016575	1·93	1·47
xenon	5·80	−111	−106	0·0051	·	·

[1] 1 kJ/(kg K) = 0·2388 kcal/(kg K)

[2] at t = 100°C

TABLES

Alloys

Z 11

alloy	parts by mass / (average values)								
	Cu	Zn	Pb	Sn	Sb	Al	Fe	Ni	P	other
aluminium-brass	60	32				8				
aluminium-bronze	98..82					2...18				
anti friction metal	5		85		10					
brass	80..57	20..43								
bronze	80..83			20...17						
delta metal	55..63	43..36				0...1	0...1·5	...0·06	...0·01	Mn:~1
German silver	50	30						20		
hard brass	60..56	38..43	2...1							
hard red brass	70	9	7	9		5				
magnalium						80				Mg:20
monel metal	30							70		
nickel-brass	50	39·4	0·1				0·5	10	...0·8	
nickel-bronze	50...70							50...30		
nickel-copper	79						4	15		Mn: 2
phosphorus-bronze	96..90	0...4		7...11						
pinchbeck or tombac	80...95	20...5								
red brass	82...86	0...6	0...0·1	16...8						
silver-tin alloy				95						Ag: 5
spec. bronze f. bearings	82		16·5	1				0·5		
white metal	5...9			80...73	10...18					

Z 12

TABLES

Heat values

Latent heat of fusion per unit mass l_f

material	$\frac{kJ}{kg}$[1]	material	$\frac{kJ}{kg}$[1]	material	$\frac{kJ}{kg}$[1]
aluminium	377	glycerine	176	paraffin	147
antimony	164	gold	67	phenol	109
brass	168	ice	335	platinum	113
cadmium	46	iron	205	potassium	59
cast iron	126	lead	23	silver	109
chromium	134	manganese	155	sulphur	38
cobalt	243	mercury	11·7	tin	59
copper	172	naphthaline	151	Wood's alloy	33·5
ethyl ether	113	nickel	234	zinc	117

Latent heat of evaporation per unit mass l_d at 101 32 kN/m² (= 760 torr)

material	$\frac{kJ}{kg}$[1]	material	$\frac{kJ}{kg}$[1]	material	$\frac{kJ}{kg}$[1]
alcohol	880	hydrogen	503	oxygen	214
ammonia	1410	mercury	281	sulph. dioxide	402
carb. dioxide	595	methyl chlor.	406	toluene	365
chlorine	293	nitrogen	201	water	2250

Gas constant R in J/kg K[2] and relative molecular mass M_r

material	R	M_r	material	R	M_r	material	R	M_r
acetylene	319		carb acid	186	44	nitrogen	297	28
air	288	29	carb monox.	297	28	oxygen	260	32
ammonia	489	17	hydrogen	4120	2	sulph. acid	130	64

Linear coefficient of expansion α in $1/10^6$ K

material	α	material	α	material	α
aluminium	23·8	German silver	18·0	porcelain	4·0
bismuth	13·5	gold	14·2	quartz glass	0·5
brass	18·5	lead	29·0	silver	19·7
bronze	17·5	molybdenum	5·2	steatite	8·5
cadmium	30·0	nickel	13·0	steel, mild	12·0
cast iron	10·5	nickel steel		tin	23·0
constantan	15·2	= Invar at 36%	1·5	tungsten	4·5
copper	16·5	platinum	9·0	zinc	30·0

Cubic coefficient of expansion γ in 1/K

material	γ	material	γ	material	γ
alcohol	0·0011	glycerine	0·0005	petroleum	0·001
benzene	0·001	mercury	0·00018	toluene	0·00108
ether	0·0016	oil of turp.	0·001	water	0·00018

[1] 1 kJ/kg = 0·2388 kcal/kg

[2] 1 J/kg K = 0·102 kgf m/kg°C

TABLES

Heat values

Z 13

Heat transfer coefficients α in $W/(m^2K)$

water below boiling point	$349 + 2093\sqrt{\upsilon}$
boiling water	4 660
condensed vapour	10 000
air at 98·1 kN/m^2 for $\upsilon \geqq 5$ m/s (Russell formula)	$6 + 4\upsilon$

υ : velocity of water or air in m/s

Coefficient of heat transmission k in $W/(m^2K)$

material	thickness of insulating layer (cm)							
	0·3	1	2	5	12	25	38	51
reinforced concrete				4·3	3·5			
glass	5·8	5·5						
timber wall			3·8	2·4	1·7			
chalky sandstone					3·1	2·2	1·7	1·4
gravel concrete				4·1	3·4	2·3		
slag concrete					2·7	1·7	1·4	1·0
brick					2·9	2·0	1·5	1·3

single window, puttied	5·9
double window, 2 cm spacing, puttied	2·9
double window, 12 cm spacing, puttied	2·3
tiled roof without/with joint packing	11·6/5·8

Radiation constant C in $\times 10^{-8}$ $W/(m^2K^4)$

silver	1·2	iron polish.	11·5	timber	51
copper	2·3	iron unpol.	15·1	glass	52
brass polished	3·0	ice	35	brickwork	52
aluminium polish.	3·0	water	37	absolutely black surf.	56·7
aluminium unpol.	4·0	soot	47		

Colours of glowing steel and associated temperatures in degrees centigrade

dark-red	680	yellowish red	950
dark cherry-red	740	yellow	1 000
cherry-red	770	light-yellow	1 100
light cherry-red	800	yellowish white	1 200
light-red	850	white	1 300
light light-red	900		and above

Drawing colours of steel and associated temperatures in degrees centigrade

pale yellow	200	purple	260	light-blue	320
straw-yellow	220	violet	280	bluish gray	350
brown	240	corn-flower blue	300	gray	400

TABLES

Mechanical properties of solids

Permissible stresses in MN/m² or N/mm²

material	modulus of elastic. E	type of *) load	tensile p_t	bending tension p_{bt}	bending compr p_{bc}	compr. p_c	shear p_q	torsion p_{qt}	contact pressure p_b
mild steel BS 15	210 000	I	100 - 150				72 - 110	65 - 95	80 - 120
		II	65 - 95				48 - 75	40 - 60	50 - 70
		III	45 - 70				35 - 50	30 - 45	27 - 33
mild steel BS 968	210 000	I	140 - 210				96 - 144	85 - 125	100 - 150
		II	90 - 135			-	64 - 96	55 - 85	70 - 100
		III	65 - 95				32 - 48	40 - 60	36 - 50
steel casting Fe_{cast} 38	220 000	I	60 - 120		90 - 150		72 - 95	36 - 48	80 - 100
		II	40 - 80		60 - 100		48 - 64	24 - 32	53 - 67
		III	20 - 40		-		24 - 32	12 - 16	27 - 33
BS 1452 Grade 10	100 000	I	35 - 45		85 - 115		35 - 50	30 - 45	-
		II	27 - 37		55 - 75		25 - 35	20 - 30	-
		III	20 - 30		20 - 30		20 - 25	15 - 20	-
white mall. iron BS 309 Grade W22/4	-	I	45 - 70		60 - 90		-	30 - 40	50 - 80
		II	30 - 47		40 - 60		-	20 - 27	33 - 53
		III	15 - 23		-		-	10 - 13	17 - 27
copper rolled	110 000	I	40 - 54				-	-	35 - 50
		II	27 - 36				-	-	23 - 33
		III	13 - 18		-		-	-	12 - 17
phosphor-bronze	90 000	I	60 - 90				45 - 70		50 - 75
		II	40 - 60		-		30 - 47		33 - 50
		III	20 - 30		-		15 - 23		17 - 25

*) see P 1

Permissible bending and shear stresses for elastic materials in MN/m² or N/mm²

(p_{bt} and p_{qt})

material	modulus of elasticity E	type of load+)	p_{bt} – values A	B	C	modulus of rigidity G	p_{qt} – values
spring steel	210 000	I	1000	500	150	80 000	650
		II	750	350	120		500
		III	500	250	80		350
pinchbeck or tombac	100 000	I	200	100	40	38 500	120
		II	150	80	30		100
		III	100	50	20		80
German silver	125 000	I	300	150	50	46 000	200
		II	250	120	40		180
		III	200	100	30		150
phosphor-bronze	110 000	I	200	100	40	41 000	120
		II	150	80	30		100
		III	100	50	20		80
nickeline	130 000	I	300	150	50	48 000	200
		II	220	110	40		180
		III	150	80	30		150

+) see note to P 1

A : for simple springs
B : for bent and curved springs
C : for springs with no secondary effect

Coefficient of friction

Coefficients of sliding and static friction

material	on material	sliding friction μ			static friction μ_0		
		dry	on water	with lubrication	dry	on water	with lubrication
bronze	bronze	0·20	0·10	0·06			0·11
	cast iron	0·18		0·08			
	steel	0·18		0·07	0·19		
oak	oak ||	0·50			0·60		
	oak #	0·30			0·50		
cast iron	cast iron		0·31	0·10			0·16
	steel	0·18			0·33		
rubber	asphalt	0·50	0·30	0·20			
	concrete	0·60	0·50	0·30			
hemp rope	timber				0·50		
leather belt	oak	0·40			0·50		
	cast iron	0·40	0·40	0·20	0·40	0·50	0·12
steel	oak		0·26	0·08		0·65	0·11
	ice	0·014			0·027		
	steel	0·10		0·10	0·15		0·12

Rolling friction

(for section K 12 and L 9)

material on material	lever arm f of frictional force in mm
rubber on on asphalt	0·010
rubber on concrete	0·015
lignum vitae on lignum vitae	0·050
steel on steel (hard: ball bearing)	0·001
steel on steel (soft)	0·005
elm on lignum vitae	0·080

|| : movement with grain of both materials

: movement perpendicular to grain of sliding body

TABLES

Lighting values

Z 17

Mean illumination E_v in lux

type of establishment or location		general lighting only	general and spec. lighting	
			bench	general
workshops according to work done	rough	80	100	20
	medium	160	400	40
	precise	300	1 000	80
	very prec.	600	4 000	300
living rooms where lighting is	weak	40		
	medium	80		
	bright	150		
streets and squares etc.	light	5		
	medium	10		
where traffic flow is	heavy	20		
	citytraff.	40		
factory yards where traffic	light	5		
	heavy	20		

Luminous efficacy η

type of lighting	colour of illuminated surface		
	light	medium	dark
direct	0·50	0·40	0·30
indirect	0·35	0·20	0·05

	deep bowl	widespread
	reflector	
street lighting	0·45	0·40

Luminous flux ϕ_v of lamps

standard lamps with single coiled filament (at operating voltage)	P_{el} in W	15	25	40	60	75	100
	ϕ_v in klm	0·12	0·23	0·43	0·73	0·96	1·38
	P_{el} in W	150	200	300	500	1000	2000
	ϕ_v in klm	2·22	3·15	5·0	8·4	18·8	40·0
tubular fluorescent lamps of 38 mm diameter	P_{el} in W	15	20	25	40	65	
	ϕ_v in klm	0·59	1·22	1·71	2·98	4·78	
high-pressure lamps filled with mercury vapour	P_{el} in W	125	250	400	700	1000	2000
	ϕ_v in klm	5·6	12	21	37	52	125

P_{el} : electrical power

Z18

TABLES

Circular functions

	SINE							
	0′	10′	20′	30′	40′	50′	60′	
0	0·0000	0·0029	0·0058	0·0087	0·0116	0·0145	0·0175	89
1	0·0175	0·0204	0·0233	0·0262	0·0291	0·0320	0·0349	88
2	0·0349	0·0378	0·0407	0·0436	0·0465	0·0494	0·0523	87
3	0·0523	0·0552	0·0581	0·0610	0·0640	0·0669	0·0698	86
4	0·0698	0·0727	0·0756	0·0785	0·0814	0·0843	0·0872	85
5	0·0872	0·0901	0·0929	0·0958	0·0987	0·1016	0·1045	84
6	0·1045	0·1074	0·1103	0·1132	0·1161	0·1190	0·1219	83
7	0·1219	0·1249	0·1276	0·1305	0·1334	0·1363	0·1392	82
8	0·1392	0·1421	0·1449	0·1478	0·1507	0·1536	0·1564	81
9	0·1564	0·1593	0·1622	0·1650	0·1679	0·1708	0·1736	80
10	0·1736	0·1765	0·1794	0·1922	0·1851	0·1880	0·1908	79
11	0·1908	0·1937	0·1965	0·1994	0·2022	0·2051	0·2079	78
12	0·2079	0·2108	0·2136	0·[illegible]64	0·2193	0·2221	0·2250	77
13	0·2250	0·2278	0·2306	0·[illegible]34	0·2363	0·2391	0·2419	76
14	0·2419	0·2447	0·2476	0·2504	0·2532	0·2560	0·2588	75
15	0·2588	0·2616	0·2644	0·2672	0·2700	0·2728	0·2756	74
16	0·2756	0·2784	0·2812	0·2840	0·2868	0·2896	0·2924	73
17	0·2924	0·2952	0·2979	0·3007	0·3035	0·3062	0·3090	72
18	0·3090	0·3118	0·3145	0·3173	0·3201	0·3228	0·3256	71
19	0·3256	0·3283	0·3311	0·3338	0·3365	0·3393	0·3420	70
20	0·3420	0·3448	0·3475	0·3502	0·3529	0·3557	0·3584	69
21	0·3584	0·3611	0·3638	0·3665	0·3692	0·3719	0·3746	68
22	0·3746	0·3773	0·3800	0·3827	0·3854	0·3881	0·3907	67
23	0·3907	0·3934	0·3961	0·3987	0·4014	0·4041	0·4067	66
24	0·4067	0·4094	0·4120	0·4147	0·4173	0·4200	0·4226	65
25	0·4226	0·4253	0·4279	0·4305	0·4331	0·4358	0·4384	64
26	0·4384	0·4410	0·4436	0·4462	0·4488	0·4514	0·4540	63
27	0·4540	0·4566	0·4592	0·4617	0·4643	0·4669	0·4695	62
28	0·4695	0·4720	0·4746	0·4772	0·4797	0·4823	0·4848	61
29	0·4848	0·4874	0·4899	0·4924	0·4950	0·4975	0·5000	60
30	0·5000	0·5025	0·5050	0·5075	0·5100	0·5125	0·5150	59
31	0·5150	0·5175	0·5200	0·5225	0·5250	0·5275	0·5299	58
32	0·5299	0·5324	0·5348	0·5373	0·5398	0·5422	0·5446	57
33	0·5446	0·5471	0·5495	0·5519	0·5544	0·5568	0·5592	56
34	0·5592	0·5616	0·5640	0·5664	0·5688	0·5712	0·5736	55
35	0·5736	0·5760	0·5783	0·5807	0·5831	0·5854	0·5878	54
36	0·5878	0·5901	0·5925	0·5948	0·5972	0·5995	0·6018	53
37	0·6018	0·6041	0·6065	0·6088	0·6111	0·6134	0·6157	52
38	0·6157	0·6180	0·6202	0·6225	0·6248	0·6271	0·6293	51
39	0·6293	0·6316	0·6338	0·6361	0·6383	0·6406	0·6428	50
40	0·6428	0·6450	0·6472	0·6494	0·6517	0·6539	0·6561	49
41	0·6561	0·6583	0·6604	0·6626	0·6648	0·6670	0·6691	48
42	0·6691	0·6713	0·6734	0·6756	0·6777	0·6799	0·6820	47
43	0·6820	0·6841	0·6862	0·6884	0·6905	0·6926	0·6947	46
44	0·6947	0·6967	0·6988	0·7009	0·7030	0·7050	0·7071	45
	60′	50′	40′	30′	20′	10′	0′	DE-GREE

COSINE

TABLES

Circular functions

Z 19

	COSINE							
DE-GREE	0'	10'	20'	30'	40'	50'	60'	
0	1·0000	1·0000	1·0000	1·0000	0·9999	0·9999	0·9998	89
1	0·9998	0·9998	0·9997	0·9997	0·9996	0·9995	0·9994	88
2	0·9994	0·9993	0·9992	0·9990	0·9989	0·9988	0·9986	87
3	0·9986	0·9985	0·9983	0·9981	0·9980	0·9978	0·9976	86
4	0·9976	0·9974	0·9971	0·9969	0·9967	0·9964	0·9962	85
5	0·9962	0·9959	0·9957	0·9954	0·9951	0·9948	0·9945	84
6	0·9945	0·9942	0·9939	0·9936	0·9932	0·9929	0·9925	83
7	0·9925	0·9922	0·9918	0·9914	0·9911	0·9907	0·9903	82
8	0·9903	0·9899	0·9894	0·9890	0·9886	0·9881	0·9877	81
9	0·9877	0·9872	0·9868	0·9863	0·9858	0·9853	0·9848	80
10	0·9848	0·9843	0·9838	0·9833	0·9827	0·9822	0·9816	79
11	0·9816	0·9811	0·9805	0·9799	0·9793	0·9787	0·9781	78
12	0·9781	0·9775	0·9769	0·9763	0·9757	0·9750	0·9744	77
13	0·9744	0·9737	0·9730	0·9724	0·9717	0·9710	0·9703	76
14	0·9703	0·9696	0·9689	0·9681	0·9674	0·9667	0·9659	75
15	0·9659	0·9652	0·9644	0·9636	0·9628	0·9621	0·9613	74
16	0·9613	0·9605	0·9596	0·9588	0·9580	0·9572	0·9563	73
17	0·9563	0·9555	0·9546	0·9537	0·9528	0·9520	0·9511	72
18	0·9511	0·9502	0·9492	0·9483	0·9474	0·9465	0·9455	71
19	0·9455	0·9446	0·9436	0·9426	0·9417	0·9407	0·9397	70
20	0·9397	0·9387	0·9377	0·9367	0·9356	0·9346	0·9336	69
21	0·9336	0·9325	0·9315	0·9304	0·9293	0·9283	0·9272	68
22	0·9272	0·9261	0·9250	0·9239	0·9228	0·9216	0·9205	67
23	0·9205	0·9194	0·9182	0·9171	0·9159	0·9147	0·9135	66
24	0·9135	0·9124	0·9112	0·9100	0·9088	0·9075	0·9063	65
25	0·9063	0·9051	0·9038	0·9026	0·9013	0·9001	0·8988	64
26	0·8988	0·8975	0·8962	0·8949	0·8936	0·8923	0·8910	63
27	0·8910	0·8897	0·8884	0·8870	0·8857	0·8843	0·8829	62
28	0·8829	0·8816	0·8802	0·8788	0·8774	0·8760	0·8746	61
29	0·8746	0·8732	0·8718	0·8704	0·8689	0·8675	0·8660	60
30	0·8660	0·8646	0·8631	0·8616	0·8601	0·8587	0·8572	59
31	0·8572	0·8557	0·8542	0·8526	0·8511	0·8496	0·8480	58
32	0·8480	0·8465	0·8450	0·8434	0·8418	0·8403	0·8387	57
33	0·8387	0·8371	0·8355	0·8339	0·8323	0·8307	0·8290	56
34	0·8290	0·8274	0·8258	0·8241	0·8225	0·8208	0·8192	55
35	0·8192	0·8175	0·8158	0·8141	0·8124	0·8107	0·8090	54
36	0·8090	0·8073	0·8056	0·8039	0·8021	0·8004	0·7986	53
37	0·7986	0·7969	0·7951	0·7934	0·7916	0·7898	0·7880	52
38	0·7880	0·7862	0·7844	0·7826	0·7808	0·7790	0·7771	51
39	0·7771	0·7753	0·7735	0·7716	0·7698	0·7679	0·7660	50
40	0·7660	0·7642	0·7623	0·7604	0·7585	0·7566	0·7547	49
41	0·7547	0·7528	0·7509	0·7490	0·7470	0·7451	0·7431	48
42	0·7431	0·7412	0·7392	0·7373	0·7353	0·7333	0·7314	47
43	0·7314	0·7294	0·7274	0·7254	0·7234	0·7214	0·7193	46
44	0·7193	0·7173	0·7153	0·7133	0·7112	0·7092	0·7071	45
	60'	50'	40'	30'	20'	10'	0'	DE-GREE
				SINE				

Z 20 TABLES

Circular functions

DE-GREE				TAN				
	0'	10'	20'	30'	40'	50'	60'	
0	0·0000	0·0029	0·0058	0·0087	0·0116	0·0145	0·0175	89
1	0·0175	0·0204	0·0233	0·0262	0·0291	0·0320	0·0349	88
2	0·0349	0·0378	0·0407	0·0437	0·0466	0·0495	0·0524	87
3	0·0524	0·0553	0·0582	0·0612	0·0641	0·0670	0·0699	86
4	0·0699	0·0729	0·0758	0·0787	0·0816	0·0846	0·0875	85
5	0·0875	0·0904	0·0934	0·0963	0·0992	0·1022	0·1051	84
6	0·1051	0·1080	0·1110	0·1139	0·1169	0·1198	0·1228	83
7	0·1228	0·1257	0·1287	0·1317	0·1346	0·1376	0·1405	82
8	0·1405	0·1435	0·1465	0·1495	0·1524	0·1554	0·1584	81
9	0·1584	0·1614	0·1644	0·1673	0·1703	0·1733	0·1763	80
10	0·1763	0·1793	0·1823	0·1853	0·1883	0·1914	0·1944	79
11	0·1944	0·1974	0·2004	0·2035	0·2065	0·2095	0·2126	78
12	0·2126	0·2156	0·2186	0·2217	0·2247	0·2278	0·2309	77
13	0·2309	0·2339	0·2370	0·2401	0·2432	0·2462	0·2493	76
14	0·2493	0·2524	0·2555	0·2586	0·2617	0·2648	0·2679	75
15	0·2679	0·2711	0·2742	0·2773	0·2805	0·2836	0·2867	74
16	0·2867	0·2899	0·2931	0·2962	0·2994	0·3026	0·3057	73
17	0·3057	0·3089	0·3121	0·3153	0·3185	0·3217	0·3249	72
18	0·3249	0·3281	0·3314	0·3346	0·3378	0·3411	0·3443	71
19	0·3443	0·3476	0·3508	0·3541	0·3574	0·3607	0·3640	70
20	0·3640	0·3673	0·3706	0·3739	0·3772	0·3805	0·3839	69
21	0·3839	0·3872	0·3906	0·3939	0·3973	0·4006	0·4040	68
22	0·4040	0·4074	0·4108	0·4142	0·4176	0·4210	0·4245	67
23	0·4245	0·4279	0·4314	0·4348	0·4383	0·4417	0·4452	66
24	0·4452	0·4487	0·4522	0·4557	0·4592	0·4628	0·4663	65
25	0·4663	0·4699	0·4734	0·4770	0·4806	0·4841	0·4877	64
26	0·4877	0·4913	0·4950	0·4986	0·5022	0·5059	0·5095	63
27	0·5095	0·5132	0·5169	0·5206	0·5243	0·5280	0·5317	62
28	0·5317	0·5354	0·5392	0·5430	0·5467	0·5505	0·5543	61
29	0·5543	0·5581	0·5619	0·5658	0·5696	0·5735	0·5774	60
30	0·5774	0·5812	0·5851	0·5890	0·5930	0·5969	0·6009	59
31	0·6009	0·6048	0·6088	0·6128	0·6168	0·6208	0·6249	58
32	0·6249	0·6289	0·6330	0·6371	0·6412	0·6453	0·6494	57
33	0·6494	0·6536	0·6577	0·6619	0·6661	0·6703	0·6745	56
34	0·6745	0·6787	0·6830	0·6873	0·6916	0·6959	0·7002	55
35	0·7002	0·7046	0·7089	0·7133	0·7177	0·7221	0·7265	54
36	0·7265	0·7310	0·7355	0·7400	0·7445	0·7490	0·7536	53
37	0·7536	0·7581	0·7627	0·7673	0·7720	0·7766	0·7813	52
38	0·7813	0·7860	0·7907	0·7954	0·8002	0·8050	0·8093	51
39	0·8098	0·8146	0·8195	0·8243	0·8292	0·8342	0·8391	50
40	0·8391	0·8441	0·8491	0·8541	0·8591	0·8642	0·8693	49
41	0·8693	0·8744	0·8796	0·8847	0·8899	0·8952	0·9004	48
42	0·9004	0·9057	0·9110	0·9163	0·9217	0·9271	0·9325	47
43	0·9325	0·9360	0·9435	0·9490	0·9545	0·9601	0·9657	46
44	0·9657	0·9713	0·9770	0·9827	0·9884	0·9942	1·0000	45
	60'	50'	40'	30'	20'	10'	0'	DE-GREE
				COTAN				

TABLES

Circular functions

Z 21

DEGREE	COTAN							
	0'	10'	20'	30'	40'	50'	60'	
0	∞	343·77	171·89	114·59	85·940	68·750	57·290	89
1	57·290	49·104	42·964	38·188	34·368	31·242	28·636	88
2	28·636	26·432	24·542	22·904	21·470	20·206	19·081	87
3	19·081	18·075	17·169	16·350	15·605	14·924	14·301	86
4	14·301	13·727	13·197	12·706	12·251	11·826	11·430	85
5	11·430	11·059	10·712	10·385	10·078	9·7882	9·5144	84
6	9·5144	9·2553	9·0098	8·7769	8·5556	8·3450	8·1443	83
7	8·1443	7·9530	7·7703	7·5957	7·4287	7·2687	7·1154	82
8	7·1154	6·9682	6·8269	6·6912	6·5605	6·4348	6·3137	81
9	6·3137	6·1970	6·0844	5·9758	5·8708	5·7694	5·6713	80
10	5·6713	5·5764	5·4845	5·3955	5·3093	5·2257	5·1446	79
11	5·1446	5·0658	4·9894	4·9152	4·8430	4·7729	4·7046	78
12	4·7046	4·6382	4·5736	4·5107	4·4494	4·3897	4·3315	77
13	4·3315	4·2747	4·2193	4·1653	4·1126	4·0611	4·0108	76
14	4·0108	3·9616	3·9136	3·8667	3·8208	3·7759	3·7320	75
15	3·7320	3·6891	3·6470	3·6059	3·5656	3·5261	3·4874	74
16	3·4874	3·4495	3·4124	3·3759	3·3402	3·3052	3·2709	73
17	3·2709	3·2371	3·2041	3·1716	3·1397	3·1084	3·0777	72
18	3·0777	3·0475	3·0178	2·9887	2·9600	2·9319	2·9042	71
19	2·9042	2·8770	2·8502	2·8239	2·7980	2·7725	2·7475	70
20	2·7475	2·7228	2·6985	2·6746	2·6511	2·6279	2·6051	69
21	2·6051	2·5826	2·5605	2·5386	2·5172	2·4960	2·4751	68
22	2·4751	2·4545	2·4342	2·4142	2·3945	2·3750	2·3558	67
23	2·3558	2·3369	2·3183	2·2998	2·2817	2·2637	2·2460	66
24	2·2460	2·2286	2·2113	2·1943	2·1775	2·1609	2·1445	
25	2·1445	2·1283	2·1123	2·0965	2·0809	2·0655	2·0503	64
26	2·0503	2·0353	2·0204	2·0057	1·9912	1·9768	1·9626	63
27	1·9626	1·9486	1·9347	1·9210	1·9074	1·8940	1·8807	62
28	1·8807	1·8676	1·8546	1·8418	1·8291	1·8165	1·8040	61
29	1·8040	1·7917	1·7796	1·7675	1·7556	1·7438	1·7320	60
30	1·7320	1·7205	1·7090	1·6977	1·6864	1·6753	1·6643	59
31	1·6643	1·6534	1·6426	1·6318	1·6212	1·6107	1·6003	58
32	1·6003	1·5900	1·5798	1·5697	1·5597	1·5497	1·5399	57
33	1·5399	1·5301	1·5204	1·5108	1·5013	1·4919	1·4826	56
34	1·4826	1·4733	1·4641	1·4550	1·4460	1·4370	1·4281	55
35	1·4281	1·4193	1·4106	1·4019	1·3934	1·3848	1·3764	54
36	1·3764	1·3680	1·3597	1·3514	1·3432	1·3351	1·3270	53
37	1·3270	1·3190	1·3111	1·3032	1·2954	1·2876	1·2799	52
38	1·2799	1·2723	1·2647	1·2572	1·2497	1·2423	1·2349	51
39	1·2349	1·2276	1·2203	1·2131	1·2059	1·1988	1·1918	50
40	1·1918	1·1847	1·1778	1·1708	1·1640	1·1571	1·1504	49
41	1·1504	1·1436	1·1369	1·1303	1·1237	1·1171	1·1106	48
42	1·1106	1·1041	1·0977	1·0913	1·0850	1·0786	1·0724	47
43	1·0724	1·0661	1·0599	1·0538	1·0477	1·0416	1·0355	46
44	1·0355	1·0295	1·0235	1·0176	1·0117	1·0058	1·0000	45
	60'	50'	40'	30'	20'	10'	0'	DEGREE
	TAN							

CamScanner

Z 22

TABLES

Natural logs (to base e)

ln x 0.0 to 49.9 ln x

x	0	1	2	3	4	5	6	7	8	9
	−∞	−2·303	−1·609	−1·204	−0·916	−0·693	−0·511	−0·357	−0·223	−0·105
1·	0·0000	0953	1823	2624	3365	4055	4700	5306	5878	6419
2·	6931	7419	7885	8329	8755	9163	9555	9933	.0296	.0647
3·	1·0986	1314	1632	1939	2238	2528	2809	3083	3350	3610
4·	3863	4110	4351	4586	4816	5041	5261	5476	5686	5892
5·	6094	6292	6487	6677	6864	7047	7228	7405	7579	7750
6·	7918	8083	8245	8405	8563	8718	8871	9021	9169	9315
7·	9459	9601	9741	9879	.0015	.0149	.0281	.0412	.0541	.0669
8·	2·0794	0919	1041	1163	1282	1401	1518	1633	1748	1861
9·	1972	2083	2192	2300	2407	2513	2618	2721	2824	2925
10·	2·3026	3125	3224	3321	3418	3514	3609	3702	3795	3888
11·	3979	4069	4159	4248	4336	4423	4510	4596	4681	4765
12·	4849	4932	5014	5096	5177	5257	5337	5416	5494	5572
13·	5649	5726	5802	5878	5953	6027	6101	6174	6247	6319
14·	6391	6462	6532	6603	6672	6741	6810	6878	6946	7014
15·	2·7081	7147	7213	7279	7344	7408	7473	7537	7600	7663
16·	7726	7788	7850	7912	7973	8034	8094	8154	8214	8273
17·	8332	8391	8449	8507	8565	8622	8679	9736	8792	8048
18·	8904	8959	9014	9069	9124	9178	9232	9285	9339	9392
19·	9444	9497	9549	9601	9653	9704	9755	9806	9857	9907
20·	2·9957	.0007	.0057	.0106	.0155	.0204	.0253	.0301	.0350	.0397
21·	3·0445	0493	0540	0587	0634	0681	0727	0773	0819	0865
22·	0910	0956	1001	1046	1091	1135	1179	1224	1268	1311
23·	1355	1398	1442	1485	1527	1570	1612	1655	1697	1739
24·	1781	1822	1864	1905	1946	1987	2027	2068	2108	2149
25·	3·2189	2229	2268	2308	2347	2387	2426	2465	2504	2542
26·	2581	2619	2658	2696	2734	2771	2809	2847	2884	2921
27·	2958	2995	3032	3069	3105	3142	3178	3214	3250	3286
28·	3322	3358	3393	3429	3464	3499	3534	3569	3604	3638
29·	3673	3707	3742	3776	3810	3844	3878	3911	3945	3979
30·	3·4012	4045	4078	4111	4144	4177	4210	4243	4275	4308
31·	4340	4372	4404	4436	4468	4500	4532	4563	4595	4626
32·	4657	4689	4720	4751	4782	4812	4843	4874	4904	4935
33·	4965	4995	5025	5056	5086	5115	5145	5175	5205	5234
34·	5264	5293	5322	5351	5381	5410	5439	5467	5496	5525
35·	3·5553	5582	5610	5639	5667	5695	5723	5752	5779	5807
36·	5835	5863	5891	5918	5946	5973	6000	6028	6055	6082
37·	6109	6136	6163	6190	6217	6243	6270	6297	6323	6350
38·	6376	6402	6428	6454	6481	6507	6533	6558	6584	6610
39·	6636	6661	6687	6712	6738	6763	6788	6814	6839	6864
40·	3·6889	6914	6939	6964	6988	7013	7038	7062	7087	7111
41·	7136	7160	7184	7209	7233	7257	7281	7305	7329	7353
42·	7377	7400	7424	7448	7471	7495	7519	7542	7565	7589
43·	7612	7635	7658	7682	7705	7728	7751	7773	7796	7819
44·	7842	7865	7887	7910	7932	7955	7977	8000	8022	8044
45·	3·8067	8089	8111	8133	8155	8177	8199	8221	8243	8265
46·	8286	8308	8330	8351	8373	8395	8416	8437	8459	8480
47·	8501	8523	8544	8565	8586	8607	8628	8649	8670	8691
48·	8712	8733	8754	8774	8795	8816	8836	8857	8877	8898
49·	8918	8939	8959	8979	9000	9020	9040	9060	9080	9100

TABLES

Natural logs (to base e)

Z 23

ln x 50 to 499 ln x

x	0	1	2	3	4	5	6	7	8	9
5	3·9120	9318	9512	9703	9890	·0073	·0254	·0431	·0604	·0775
6	4·0943	1109	1271	1431	1589	1744	1897	2047	2195	2341
7	2485	2627	2767	2905	3041	3175	3307	3438	3567	3694
8	3820	3944	4067	4188	4308	4427	4543	4659	4773	4886
9	4998	5109	5218	5326	5433	5539	5643	5747	5850	5951
10	4·6052	6151	6250	6347	6444	6540	6634	6728	6821	6913
11	7005	7095	7185	7274	7362	7449	7536	7622	7707	7791
12	7875	7958	8040	8122	8203	8283	8363	8442	8520	8598
13	8675	8752	8828	8903	8978	9053	9127	9200	9273	9345
14	9416	9488	9558	9628	9698	9767	9836	9904	9972	·0039
15	5·0106	0173	0239	0304	0370	0434	0499	0562	0626	0689
16	·0752	0814	0876	0938	0999	1059	1120	1180	1240	1299
17	1358	1417	1475	1533	1591	1648	1705	1761	1818	1874
18	1930	1985	2040	2095	2149	2204	2257	2311	2364	2417
19	2470	2523	2575	2627	2679	2730	2781	2832	2883	2933
20	5·2983	3033	3083	3132	3181	3230	3279	3327	3375	3423
21	3471	3519	3566	3613	3660	3706	3753	3799	3845	3891
22	3936	3982	4027	4072	4116	4161	4205	4250	4293	4337
23	4381	4424	4467	4510	4553	4596	4638	4681	4723	4765
24	4806	4848	4889	4931	4972	5013	5053	5094	5134	5175
25	5·5215	5255	5294	5334	5373	5413	5452	5491	5530	5568
26	5607	5645	5683	5722	5759	5797	5835	5872	5910	5947
27	5984	6021	6058	6095	6131	6168	6204	6240	6276	6312
28	6348	6384	6419	6454	6490	6525	6560	6595	6630	6664
29	6699	6733	6768	6802	6836	6870	6904	6937	6971	7004
30	5·7038	7071	7104	7137	7170	7203	7236	7268	7301	7333
31	7366	7398	7430	7462	7494	7526	7557	7589	7621	7652
32	7683	7714	7746	7777	7807	7838	7869	7900	7930	7961
33	7991	8021	8051	8081	8111	8141	8171	8201	8230	8260
34	8289	8319	8348	8377	8406	8435	8464	8493	8522	8551
35	5·8579	8608	8636	8665	9693	8721	8749	8777	8805	8833
36	8861	8889	8916	8944	8972	8999	9026	9054	9081	9108
37	9135	9162	9189	9216	9243	9269	9296	9322	9349	9375
38	9402	9428	9454	9480	9506	9532	9558	9584	9610	9636
39	9661	9687	9713	9738	9764	9789	9814	9839	9865	9890
40	5·9915	9940	9965	9989	·0014	·0039	·0064	·0088	·0113	·0137
41	6·0162	0186	0210	0234	0259	0283	0307	0331	0355	0379
42	0403	0426	0450	0474	0497	0521	0544	0568	0591	0615
43	0638	0661	0684	0707	0730	0753	0776	0799	0822	0845
44	0868	0890	0913	0936	0958	0981	1003	1026	1048	1070
45	6·1092	1115	1137	1159	1181	1203	1225	1247	1269	1291
46	1312	1334	1356	1377	1399	1420	1442	1463	1485	1506
47	1527	1549	1570	1591	1612	1633	1654	1675	1696	1717
48	1738	1759	1779	1800	1821	1841	1862	1883	1903	1924
49	1944	1964	1985	2005	2025	2046	2066	2086	2106	2126

$\ln 10^3 = 6{\cdot}9078$
$\ln 10^4 = 9{\cdot}2103$
$\ln 10^5 = 11{\cdot}5129$
$\ln 10^6 = 13{\cdot}8155$

EXAMPLES : $\ln 4{\cdot}426 = \ln 44{\cdot}26 - \ln 10$
$= 3{\cdot}7887 + 0{\cdot}6 \times 23\,E - \ln 10$
$= 3{\cdot}7901 - 2{\cdot}3026 = 1{\cdot}4875$

$\ln 0{\cdot}3271 = \ln 327{\cdot}1 - \ln 10^3$
$= 5{\cdot}7900 + 0{\cdot}1 \times 30\,E - \ln 10^3$
$= 5{\cdot}7903 - 6{\cdot}9078 = -1{\cdot}1175$

Z 24

TABLES

Natural logs (to base e)

ln x [illegible] 99 ln x

x	0	1	2	3	4	5	6	7	8	9
50	6·2146	2166	2186	2206	2226	2246	2265	2285	2305	2324
51	2344	2364	2383	2403	2422	2442	2461	2480	2500	2519
52	2538	2558	2577	2596	2615	2634	2653	2672	2691	2710
53	2729	2748	2766	2785	2804	2823	2841	2860	2879	2897
54	2916	2934	2953	2971	2989	3008	3026	3044	3063	3081
55	6·3099	3117	3135	3154	3172	3190	3208	3226	3244	3261
56	3279	3297	3315	3333	3351	3368	3386	3404	3421	3439
57	3456	3474	3491	3509	3526	3544	3561	3578	3596	3613
58	3630	3648	3665	3682	3699	3716	3733	3750	3767	3784
59	3801	3818	3835	3852	3869	3886	3902	3919	3936	3953
60	6·3969	3986	4003	4019	4036	4052	4069	4085	4102	4118
61	4135	4151	4167	4184	4200	4216	4232	4249	4265	4281
62	4297	4313	4329	4345	4362	4378	4394	4409	4425	4441
63	4457	4473	4489	4505	4520	4536	4552	4568	4583	4599
64	4615	4630	4646	4661	4677	4693	4708	4723	4739	4754
65	6·4770	4785	4800	4816	4831	4846	4862	4877	4892	4907
66	4922	4938	4953	4968	4983	4998	5013	5028	5043	5058
67	5073	5088	5103	5117	5132	5147	5162	5177	5191	5206
68	5221	5236	5250	5265	5280	5294	5309	5323	5338	5352
69	5367	5381	5396	5410	5425	5439	5453	5468	5482	5497
70	6·5511	5525	5539	5554	5568	5582	5596	5610	5624	5639
71	5653	5667	5681	5695	5709	5723	5737	5751	5765	5779
72	5793	5806	5820	5834	5848	5862	5876	5889	5903	5917
73	5930	5944	5958	5971	5985	5999	6012	6026	6039	6053
74	6067	6080	6093	6107	6120	6134	6147	6161	6174	6187
75	6·6201	6214	6227	6241	6254	6267	6280	6294	6307	6320
76	6333	6346	6359	6373	6386	6399	6412	6425	6438	6451
77	6464	6477	6490	6503	6516	6529	6542	6554	6567	6580
78	6593	6606	6619	6631	6644	6657	6670	6682	6695	6708
79	6720	6733	6746	6758	6771	6783	6796	6809	6821	6834
80	6·6846	6859	6871	6884	6896	6908	6921	6933	6946	6958
81	6970	6983	6995	7007	7020	7032	7044	7056	7069	7081
82	7093	7105	7117	7130	7142	7154	7166	7178	7190	7202
83	7214	7226	7238	7250	7262	7274	7286	7298	7310	7322
84	7334	7346	7358	7370	7382	7393	7405	7417	7429	7441
85	6·7452	7464	7476	7488	7499	7511	7523	7534	7546	7558
86	7569	7581	7593	7604	7616	7627	7639	7650	7662	7673
87	7685	7696	7708	7719	7731	7742	7754	7765	7776	7788
88	7799	7811	7822	7833	7845	7856	7867	7878	7890	7901
89	7912	7923	7935	7946	7957	7968	7979	7991	8002	8013
90	6·8024	8035	8046	8057	8068	8079	8090	8101	8112	8123
91	8134	8145	8156	8167	8178	8189	8200	8211	8222	8233
92	8244	8255	8265	8276	8287	8298	8309	8320	8330	8341
93	8352	8363	8373	8384	8395	8405	8416	8427	8437	8448
94	8459	8469	8480	8491	8501	8512	8522	8533	8544	8554
95	6·8565	8575	8586	8596	8607	8617	8628	8638	8648	8659
96	8669	8680	8690	8701	8711	8721	8732	8742	8752	8763
97	8773	8783	8794	8804	8814	8824	8835	8845	8855	8865
98	8876	8886	8896	8906	8916	8926	8937	8947	8957	8967
99	8977	8987	8997	9007	9017	9027	9037	9048	9058	9068

TABLES

Degrees to radians

Z 25

deg	rad	deg	rad	deg	rad	deg	rad
0	0·00 000	45	0·78 540	90	1·57 080	135	2·35 619
1	0·01 745	46	0·80 285	91	1·58 825	136	2·37 365
2	0·03 491	47	0·82 031	92	1·60 570	137	2·39 110
3	0·05 236	48	0·83 776	93	1·62 316	138	2·40 855
4	0·06 981	49	0·85 521	94	1·64 061	139	2·42 601
5	0·08 727	50	0·87 266	95	1·65 806	140	2·44 346
6	0·10 472	51	0·89 012	96	1·67 552	141	2·46 091
7	0·12 217	52	0·90 757	97	1·69 297	142	2·47 837
8	0·13 963	53	0·92 502	98	1·71 042	143	2·49 582
9	0·15 708	54	0·94 248	99	1·72 788	144	2·51 327
10	0·17 453	55	0·95 993	100	1·74 533	145	2·53 073
11	0·19 199	56	0·97 738	101	1·76 278	146	2·54 818
12	0·20 944	57	0·99 484	102	1·78 024	147	2·56 563
13	0·22 689	58	1·01 229	103	1·79 769	148	2·58 309
14	0·24 435	59	1·02 974	104	1·81 514	149	2·60 054
15	0·26 180	60	1·04 720	105	1·83 260	150	2·61 799
16	0·27 925	61	1·06 465	106	1·85 005	151	2·63 545
17	0·29 671	62	1·08 210	107	1·86 750	152	2·65 290
18	0·31 416	63	1·09 956	108	1·88 496	153	2·67 035
19	0·33 161	64	1·11 701	109	1·90 241	154	2·68 781
20	0·34 907	65	1·13 446	110	1·91 986	155	2·70 526
21	0·36 652	66	1·15 192	111	1·93 732	156	2·72 271
22	0·38 397	67	1·16 937	112	1·95 477	157	2·74 017
23	0·40 143	68	1·18 682	113	1·97 222	158	2·75 762
24	0·41 888	69	1·20 428	114	1·98 968	159	2·77 507
25	0·43 633	70	1·22 173	115	2·00 713	160	2·79 253
26	0·45 379	71	1·23 918	116	2·02 453	161	2·80 998
27	0·47 124	72	1·25 664	117	2·04 204	162	2·82 743
28	0·48 869	73	1·27 409	118	2·05 949	163	2·84 489
29	0·50 615	74	1·29 154	119	2·07 694	164	2·86 234
30	0·52 360	75	1·30 900	120	2·09 440	165	2·87 979
31	0·54 105	76	1·32 645	121	2·11 185	166	2·89 725
32	0·55 850	77	1·34 390	122	2·12 930	167	2·91 470
33	0·57 596	78	1·36 136	123	2·14 675	168	2·93 215
34	0·59 341	79	1·37 881	124	2·16 421	169	2·94 961
35	0·61 086	80	1·39 626	125	2·18 166	170	2·96 706
36	0·62 832	81	1·41 372	126	2·19 911	171	2·98 451
37	0·64 577	82	1·43 117	127	2·21 657	172	3·00 197
38	0·66 322	83	1·44 862	128	2·23 402	173	3·01 942
39	0·68 068	84	1·46 608	129	2·25 147	174	3·03 687
40	0·69 813	85	1·48 353	130	2·26 893	175	3·05 433
41	0·71 559	86	1·50 098	131	2·28 638	176	3·07 178
42	0·73 304	87	1·51 844	132	2·30 383	177	3·08 923
43	0·75 049	88	1·53 589	133	2·32 129	178	3·10 669
44	0·76 795	89	1·55 334	134	2·33 874	179	3·12 414
45	0·78 540	90	1·57 080	135	2·35 619	180	3·14 159

INDEX

acceleration L 2
– , angular L 2
– , time curve L 3, L 7
active power S 28
addendum Q 1
air, humid O 7
algebraic expressions D 3, D 13
alloys Z 11
alternating current S 13...S 26
– – bridge S 19
Ångström A 1
angular frequency S 13
annuity interest calculation D 12
annulus B 3
apparent power S 15
arc differential J 7
– length J 7
– of circle K 7
Archimedes principle N 3
area expansion O 2
– , units of A 1
arithmetic mean D 7
– series D 7
asymptote F 3
atmosphere, in meteorology O 3
– , physical O 3
– , technical O 3

barrel C 4
basic differentials H 4, H 5
– integrals J 3...J 6
beam of uniform strength P 5
beams P 4, P 5
bearing friction K 12
belt drive K 13
bending P 3
– moment K 2, P 3
– of uniform beams P 4
– stress P 3
Bernoulli's theorem N 5
bevel gears Q 3
binomial series D 8
– theorem D 4
boilers Q 12
boiling point Z 5...Z 10
Bow diagram K 6
buckling P 8
buoyancy N 3

candela T 1
capacitance S 3, S 9
– of coaxial cylinders S 9
capacitor power S 28
carat A 3
Cardan joint L 10
Cartesian cocrdinate syst. D 10
Cavalierie principle C 1
Centigrade O 3
centre of gravity J 7, J 8, K 8
centrifugal force M 5
charge S 2
chemical elements U 1
– terms U 3, U 4
choking O 5
choke coil S 23, S 24
circle B 3, F 2
– , arc of K 7
– , sector of B 3, K 7
– , segment of B 3, K 7
circular shafts P 11
circumcircle E 6
clutches Q 11
coax. cylinders, capac. of S 9
coeff. of elongation P 2
– – friction Z 16
– – heat transmission Z 13
– – restitution M 8
– – rolling friction Z 16
– – sliding Z 16
– – static friction Z 16
coercive force S 22
coil, high frequency S 21
– , low frequency S 21
coiled spring Q 7
coils, non-magnetic S 21
colours of glowing steel Z 13

complex numbers D 10, D 11
composite stresses P 9...P 11
compound interest D 12
– pendulum M 7
– wound motor S 29
compression P 2
compressive stress P 2
conductance S 2
conductivity, thermal Z 5...Z 10
cone C 2
– clutch Q 11
– , frustum C 2
– pulleys R 2
conical pendulum M 7
conversion of logarithms D 2
convex mirrors T 3
coordinate system, Cartes. D 10
– – , polar D 11
copper losses S 26
core losses S 22, S 25
cosine rule E 6
– tables Z 18, Z 19
cotan tables Z 20, Z 21
coulomb S 2
counterflow exchanger O 9
Cremona method K 6
critical speed M 6
– – by vibrations Q 10
crosshead guide Q 11
cube C 1
cubic coeff. of expansion Z 12
cuboid C 1
current S 1
– density S 2
curved beams P 12
cylinder C 2
– , hollow C 2
– , sliced C 4
cylindrical boiler Q 12

D.C. machines with commutating poles S 30
degrees to radians, tables Z 25
dedendum Q 1
density N 1, N 4, Z 5...Z 10
– , determination of N 4
deposit calculation D 12

derivative H 3
derivatives H 4...H 6
determinants D 5, D 6
dielectric constant Z 2
difference coefficient H 1
differential coefficient H 1
dioptrics T 4
direct-current machine S 29
disc clutch Q 11
distance law, optical T 2
– -time curve L 3
drive R 3
driving belt R 3
– spring Q 8
dynamic moment of inertia J 11
– viscosity N 1
dynamo sheet properties Z 4

eddy currents S 22
electric circuits S 5
– field S 9
electrical measurements S 8
– power S 1
– specif. resistance Z 1
– temp. coeff. Z 1
– work S 1
– – in an electr. field S 9
electro-magnetic rules S 10
– -motive series Z 2
elements, chemical U 1
ellipse B 3, F 4
Engler degrees N 1
enthalpy O 4
entropy O 4
epicyclic gearing Q 5
equilateral triangle B 2, D 13
equilibrium K 4
Euler formula P 8
expansion, area O 2
– , linear O 2
– of gases O 6
– , volume O 2
exponential curve F 4
– equation D 2
– functions H 5

farad S 3

flow, energy loss N 6
– , equation N 5
– , laminar N 6
– , turbulent N 6
fluid, ideal N 5
– , real N 5
flux, density S 3
– , magnetic S 10
flywheel effect M 2
focal point F 4
focus F 2
Foelmer formula Q 2
force between magn. poles S 12
– , centrifugal M 5
– , gravitational M 1
– , moment K 1
– , polygon K 2
– , units of A 2
forces composition K 2, K 3
free fall L 8
frequency L 1
– , angular S 2
– , resonant S 18
friction K 9...K 13
– , bearing K 12
– clutches Q 11
– coefficient K 9, Z 16
– , rope K 13
– , sliding K 9
frustrum of cone C 2
– of pyramid C 1
functions, exponential H 5
– , hyperbolic H 6
– , inverse trig. H 6
– , logarithmic H 6
– , trigonometrical H 5

gallon, Imperial A 5
– , United States A 5
gas constant O 4, Z 12
– laws O 4
– mixtures O 7
gauss S 3
gears Q 1
gearing, epicyclic Q 5
general equation of state O 9
generators S 30
geometric mean D 7
– series D 7
– – , applic. of D 12
golden section D 13
gradient of a curve H 1, H 2
gravitational force K 1
– pressure N 3

half-angle rule E 6
harmonic oscillation L 4
– oscillations M 6, M 7
heat conduction O 8
– exchange O 8
– exchanger O 9
– flow O 1, O 2
– , latent O 2
– , of sublimation O 2
– radiation O 8
– transfer O 8
– – coeff. O 8, O 9, Z 13
– transmission O 8, O 9
heating of masses O 1
helical spring Q 9
! henry S 4
hertz L 1
hexagon B 2
high frequency coil S 21
Hooke's joint L 10
hollow cylinder C 2
humid air O 7
hydrodynamics N 1, N 5
hydrostatics N 1...N 4
hyperbola F 3
hyperbolic functions G 1, G 2, H 6
hysteresis S 22
– power S 22
– work S 22

ideal fluid N 5
illumination T 1, Z 17
impact M 8
– , elastic M 8
– , plastic M 8
impedance S 16, S 17
incircle E 6

inclined plane K 10, L 9
induced voltage S 12
inductance S 4, S 11
induction motor S 31
inertia, dynamic moment of J 11
– moment of J 9, J 10
involute toothing Q 2
instruments, electrical S 6
integral, definite J 1
– , indefinite J 1
integration J 1, J 2
– , applicat. of J 7...J 10
– by parts J 2
– by substitution J 2
– , numerical J 8
inverse circular functions E 7
iron losses S 22
isentropic O 6
isothermal state O 6
Johnson formula P 8
joule S 1
Kelvin O 3
key joints Q 6
Kirchhoff laws S 6
laminar flow N 6
laminated leaf spring Q 7
latent heat O 2, Z 12
lattice girder K 5, K 6
leakage flux S 11
left hand rule S 10
length, units of A 1
lens equation T 4
lenses T 4
linear coeff. of expansion Z 12
– equations D 5, D 6
– expansion O 2
light refraction T 2
lighting values Z 17
logarithmic functions H 6
logarithms D 2
low frequency coils S 21
luminous efficacy Z 17
– flux T 1, Z 17
– – of lamps Z 17
– intensity T 1
– quantity T 1
machines S 10
machine tools, forces R 3
– – , power required R 4
Mac Laurin series D 8
macro photography T 4
magnetic field S 11, S 12
magn. field strength S 4, S 11, Z 3
– flux S 3, S 11
– induction S 3, S 11
magnetomotive force S 4, S 11
magnifying lens T 4
mass M 1, M 2
– , equivalent M 2
– , moment of inertia J 11, M 2, M 3
– , units of A 2
maxwell S 3
mechanical oscillation M 6
mechanisms L 10
meaning of derivative H 2, H 3
measure of plane angle E 1
measuring instruments electr. S 33
melting point Z 5...Z 10
microscope T 4
modulus of elasticity P 2
Mohr's stress circle P 13
Mollier diagram O 5
moment of a force K 1
– of inertia J 9...J 11
– theorem K 1
motion, linear L 4, L 5
– , rolling L 9
– , rotational L 4, L 6
– , simple harmonic L 7
– , sliding L 9
motor, compound wound S 29
– , direct current S 29
– , induction S 31
– , shunt S 29
– , synchronous S 31
– , three phase S 31
motors S 29...S 31
multi-disc clutch Q 11
natural logs tables Z 22...Z 24

non-magnetic coils S 21
numerical integration J 8

oblique angle triangle E 6
octagon B 2
Ohm's law S 2, S 5
optical distance law T 2
oscillation, harmonic L 4
– , mechanical M 6

Pappus theorems J 8
parabola F 2
parallelepiped C 1
parallel-flow exchanger O 9
– resistances S 6
– resonance S 18
parallelogram B 1
Pascal N 1
– -triangle D 4
Pascal's theorem N 3
pendulum M 7
– , compound M 7
– , conical M 7
– , simple M 7
– , torsional M 7
pentagon B 2
period L 1
permissible stresses Z 14, Z 15
permittivity, absolute S 9
– , relative Z 2
phase shift S 14
photometric radiation eqival. T 1
photometry T 1
physical atmosphere O 3
pH-values U 2
plane, inclined K 10
– , mirrors T 3
Poise N 1
polar coordinate system D 11
– second moment of area J 10
polygon B 2
polytropic state O 6
potential difference S 2
power M 1
– , active S 28
– factor S 28
power factor correction S 2
– , reactive S 2
– , units of A 3, A
powers D
pressure N 1, O
– , gravitational N
– , hydrostatic N
– in a compr. fluid N
– – a fluid N
prismoid C
projection, angled L 8
– , horizontal L 8
– , vertical L 8
proportional, 3 rd D 13
– , 4 th D 13
– , mean D 13
pyramid C 1
– , frustum C 1

Q factor S 14, S 18
quadratic equation D 3
quantity of electricity S 2

radians E 1
radiation coefficient O 9
– constant Z 13
radius of gyration M 2
range of an ammeter S 8
– – a voltmeter S 8
reactance S 15
reactive power S 28
reagents, chemical U 2
real fluid N 5
rectangle B 1
refractive index T 2
reluctance S 4, S 11
remanent flux density S 22
resistance S 2, S 5
– of a conductor S 5
– , moment of P 7
– , rolling K 12
– , specific R 3
resistances in series S 6, S 7
– , parallel S 6, S 7
resistor combinations S 6...S 8
resonant circuits S 18

CS CamScanner

resonant frequency S 18
restitution, coeff. of M 8
Reynolds' number N 6
right angled triangle E 2
– hand rule S 10
Ritter method K 5
Röntgen rays T 3
– unit A 1
rolling friction coeff. Z 16
– resistance K 12
root-mean-square S 13
root width of tooth Q 1
roots D 1
rope friction K 13
– operated machines K 14
rotation L 7, M 4
rotational motion L 4

safety factor P 1
Sarrus rule D 5
saw-diagram R 1
Scotch-Yoke mechanism L 10
screws K 11
second moment of area J 10
– – – volume J 11
sector of an annulus K 7
– – a circle B 3, K 7
segment of a circle B 3, K 7
– – a sphere C 3
self-induction S 12
series D 7...D 9
series, arithmetic D 7
– , geometric D 7
– , Mac Laurin D 8
– motor S 29
– resonance S 18
– , Taylor D 8, D 9
shafts Q 10
shear P 6
– resistance R 3
– stress P 6
shrinkage allowance Q 13
shrunk-on ring Q 13
shunt motor S 29
Simpson's rule J 8
sine rule E 6
– tables Z 18, Z 19
single phase-output-transf. S 32
slenderness P 8
sliced cylinder C 4
slider crank chain L 10
sliding friction coeff. Z 16
– motion L 9
specific conductance Z 1
– heat O 1, O 7, Z 5...Z 10
– lighting Z 17
– resistance Z 1
speed changing R 1, R 2
– rotational L 1
sphere C 2
– with conical boring C 3
– – cylindr. – C 3
– , zone of a C 3
spiral spring Q 8
springs Q 7...Q 9
spring, coiled Q 7
– , driving Q 8
– , helical Q 9
– , laminated leaf Q 7
– , leaf Q 7
– , spiral Q 8
– , torsion-bar Q 9
spur gears Q 1, Q 2
square B 1
– coil S 20
star-delta connection S 31
static friction coeff. Z 16
– moment of a body J 7
– – – a curve J 7
Steiner's theorem J 9, M 2
stiffness M 6
Stokes N 1
straight line F 1
strain P 2
stress P 1
– at elastic. limit P 1
– – proport. – P 1
– , bending P 3
– , compressive P 2
– , permissible P 1
– , shearing P 6
– strain diagram P 1
– , tensile P 2
– , ultimate P 1

stresses in curved beams P 12
– – rotating bodies M 5
– – shafts Q 10
substitution method J 2
synchronous motor S 31

tan tables Z 20, Z 21
tangent rule E 6
tapered keys Q 6
Taylor series D 8
technical atmosphere O 3
temperature O 1, O 3
tensile force P 1
– stress P 2
tesla S 3
thermal conductivity O 8, O 9
Z 5...Z 10
– energy O 1
– variables of state O 3
thermodynamic diagrams O 5
– sign conv. O 5
thermodynamics O 4...O 6
threephase current S 27, S 28
– motors S 31
– output transform S 32
– power, measur. S 27
time, units of A 2
tonne A 2
toroidal coil S 20
torsion P 7
– bar Q 9
– stress P 7
torsional pendulum M 7
torus C 4
total reflexion T 2
transformer S 25
– , single phase
output S 32
– switch groups S 32
– , threephase
output S 32
transmission ratios M 4
trapezium B 1, K 7
– rule J 8
triangle B 1, F 1, K 7
– , acute angle E 6
– , centroid F 1
– , equilateral B 2, D 13
– , oblique angle E 6
– , radius of incircle E 6
– , – – circum-
circle E 6
– , right angled E 2
trigonometric conversions E 5
turbulent flow N 6
two coils facing each other S 10

ungula C 4
unit of fineness A 3
units of area A 1, A 4
– – force A 2
– – length A 1, A 4
– – mass A 2...A 4
– – power A 3, A 5
– – pressure A 3
– – time A 2
– – volume A 2, A 4
– – work A 3, A 5

velocity L 2
– , angular L 2
– time curve L 3, L 7
vertex radius F 2...F 4
viscosity, dynamic N 1
– , kinematic N 1
voltage S 2
– divider S 7
voltmeter S 8, S 33
volume expansion O 2
– , units of A 2

watt S 2
wavelengths A 1, T 3
wave trap S 18
weber S 3
wedges K 11
Wheatstone bridge S 8
work M 1
– , units of A 5
worm gearing Q 4

yield point P 1

zone of a sphere C 3